Municipal Solid Waste Management and Groundwater Contamination in Limbe, Cameroon

Kommunales Abfallmanagement und Grundwasserverunreinigung in Limbe, Kamerun

Von der Fakultät für Umweltwissenschaften und Verfahrenstechnik der Brandenburgischen Technischen Universität Cottbus zur Erlangung des akademischen Grades eines Doktor rerum naturalium (Dr. rer. nat.) genehmigte Dissertation

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DECLARATRION

I hereby declare that this dissertation is the result of my original research work carried out at the Brandenburg University of Technology Cottbus, Germany within the framework of the Doctorate programme in the Faculty of Environmental Engineering.

Professor **Dr. rer. nat. habil. Hans-Jürgen Voigt**, Head of the Chair of Environmental Geology of the Brandenburg University of Technology Cottbus, is the main supervisor of this research, while Professor **Dr. Cornelius Mbifung Lambi** of the Department of Geography and former Vice-Chancellor of the University of Buea, Cameroon, is the co-supervisor.

I hereby admit that this dissertation has never been submitted in whole or in part for a degree at Brandenburg University of Technology Cottbus, or elsewhere. References to other people's research have been duly cited and acknowledged in this research work accordingly.

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DEDICATION

This dissertation is dedicated to

John Awemo (RIP) and Ruphina Awemo

Thecla Laison Cheo (RIP)

Germaine-Ashley, Erika-Kamille, Lea-Karen

and Victor Cheo

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ABSTRACT

An increase in waste production is inextricably linked to population increase and increasing civilization, and depending on the waste management approach, groundwater could be seriously affected. In Limbe, for example, waste disposal methods (sewage, littering, open dumping and burning) have led to the contamination of groundwater resources. This study aims at assessing the degree to which the Limbe waste sites conform to prescribed standards of waste site location, the extent to which the waste sites compromise or enhance groundwater protection. The study further investigates groundwater management around waste sites; investigating the factors responsible for groundwater contamination from waste sites; evaluating the extent to which past and present municipal solid waste management practices minimise or enhance groundwater contamination and suggesting possible methods (techniques) by which the existing situation can be improved. Seven groundwater samples were collected for laboratory (microbiological and physic-chemical) analyses in Cameroon and Germany. Field visits and observations made were supported by pictures and interviews. The method of waste disposal used in Limbe by LUC (until 2006) and HYSACAM (from 2006) already show negative effects on groundwater. Results of microbial analysis are higher than the standards of Cameroon, WHO and ISI 10500-91. Total *Coliform* showed values >1000CFU/100ml, *E. coli* showed up to 346CFU/100ml and others showed up to 159CFU/100ml. These excessively high values imply that water is highly contaminated biologically and so groundwater wells in Limbe are not good for human consumption. Physico-chemical analysis revealed, in most samples, values lower than the prescribed standards. However, NH_4^+ showed higher values in all samples (0.9mg/L-2.6mg/L). The high level of ammonium could be related to high production of sewage in households. L7 and L1 showed the lowest values, whereas, L6 showed the highest values in almost all microbial and physico-chemical parameters analysed. L6 was most contaminated with high values mostly exceeding the given limits. This dominant wetland area must be evacuated and water highly treated because it is very dangerous for human consumption. Vadose water in Limbe requires serious biological treatment and subsequent groundwater monitoring to minimise hazards. L7 and L1 have characteristics of Basalt and because of low level of contamination can be used as the base for comparison (that is natural water). Water must also be thoroughly treated for NH_4 contamination. Waste disposal in Limbe is poorly practised and the site used must be changed. Improved waste management schemes like waste reduction, sorting and treatment are required before final disposal. Landfill construction with emphasis on barrier, leachate and gas collection systems will be most appropriate for waste disposal and in minimising leachate spill, and groundwater and other contamination. Geological and hydrogeological maps and investigations as well as recent climatic data are needed in order to choose an appropriate site for landfill construction. Most of all groundwater monitoring and sewage collection should be a very important consideration in the Limbe Municipality. Household dump sites must be thoroughly cleaned and the public sensitised on the importance of proper waste management to reduce groundwater contamination and its effects on man and the environment.

Keywords: Municipal Solid Waste Management, Groundwater Contamination, Limbe, Cameroon

ZUSAMMENFASSUNG

Eine Zunahme der Abfallproduktion ist stark mit dem Bevölkerungswachstum und der Zivilisation verbunden. Das Grundwasser kann, abhängig vom Abfallwirtschaftsansatz, ernsthaft beeinträchtigt werden. In Limbe zum Beispiel haben die Abfallentsorgungsmethoden (Abwasser, Vermüllen, offene Deponierung und Verbrennen) zur Verschmutzung des Grundwassers geführt. In dieser Hinsicht untersucht die vorliegende Studie, inwieweit den Deponien in Limbe den vorgeschriebenen Vorgaben für Mülldeponien entsprechen. Dazu wird ermittelt, in welchem Umfang die Deponien den Grundwasserschutz gefährden oder verbessern. Des Weiteren untersucht die Studie auch die Grundwasserbewirtschaftung rund um die Deponien. Die Untersuchung der Faktoren, die zur Verschmutzung des Grundwassers führen; die Auswertung des Umfang, inwieweit die vergangene und gegenwärtige Siedlungsabfallbewirtschaftung zu Minimierung oder zu Verbesserung der Grundwasserverschmutzung führen; und Vorschläge möglicher Methoden (Techniken), durch die die bestehenden Situation verbessert werden kann, sind alles Bestandteil dieser Studie. Sieben Grundwasserproben wurden entnommen, um sie mikrobiologisch und physiko-chemisch in Kamerun und Deutschland zu analysieren. Besuche vor Ort und Beobachtungen wurden anhand von Bildern und Interviews unterstützt. Die eingesetzte Abfallbeseitigungsmethode in Limbe von LUC (bis 2006) und HYSACAM (2006 bis heute) zeigen bereits negative Auswirkungen auf das Grundwasser. Die Ergebnisse der mikrobiologischen Analysen weisen Werte über den kamerunischen Vorgaben (WHO und ISI 10500-91) auf. Gesamt-Coliforme zeigten Werte über 1000CFU/100ml, *E. coli* Werte bis zu 346CFU/100ml und andere Werte bis zu 159CFU/100ml. Dies bedeutet, dass das Wasser biologisch verschmutzt ist und somit sind die Grundwasserbrunnen in Limbe nicht mehr zum menschlichen Gebrauch geeignet sind. Physiko-chemische Analysen in den meisten Proben ergaben Werte unterhalb der vorgeschriebenen Vorgaben. NH_4^+ zeigte jedoch höhere Werte in allen Proben (0.9mg/L-2.6mg/L). Die hohe Konzentration von Ammonium könnte auf hohe Abwasserproduktion von Haushalten zurückgeführt werden. L7 und L1 zeigten die niedrigsten Werte, während L6 die höchsten Werte in fast allen mikrobiellen und physiko-chemischen Parameter aufweist. L6 ist stark kontaminiert; die Werte übersteigen meist die Grenzwerte. Diese Bereiche müssen evakuiert werden und das Wasser intensiv behandelt werden, da es sehr gefährlich zum menschlichen Verzehr ist. Die Aerationwasserzone in Limbe erfordert intensive biologische Behandlung und anschließende Grundwasserüberwachung, dadurch wird die Gefahr minimiert. L7 und L1 sind von Basalt geprägt und wegen geringer Kontamination lassen sie sich als Basis für den Vergleich (natürliches Wasser) verwenden. Das Wasser ist auch gründlich gegen NH_4-Kontamination zu behandeln. Die Abfallentsorgung in Limbe wird mangelhaft durchgeführt und die Deponien müssen geändert werden. Verbesserte Abfallwirtschaftsprogramme wie Abfallreduktion, -sortierung und -behandlung sind vor der endgültigen Entsorgung erforderlich. Deponiebau mit Schwerpunkt auf Barriere, Sickerwasser und Gassammelsysteme sind am besten für die Abfallentsorgung, die Minimierung des Sickerwassers, das Grundwasser und andere Verunreinigungen geeignet. Geologische und hydrogeologische Karten und Untersuchungen sowie aktuelle klimatischen Daten werden benötigt, um einen geeigneten Ort für einen Deponiebau zu wählen. Vor allem die Grundwasserüberwachung und Abwassersammlung sollen ein sehr wichtiger Aspekt in der Verwaltung Limbe werden. Haushaltsabfalldeponien sind gründlich zu sanieren und die Öffentlichkeit soll für die Bedeutung einer ordnungsgemäßen Müllentsorgung sensibilisiert werden, um Grundwasserverunreinigungen und deren Auswirkungen auf Mensch und Umwelt zu reduzieren.

Stichwörte: **Siedlungsabfallwirtschaft, Grundwasserverschmutzung, Limbe, Kamerun**

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ABBREVIATIONS

3Rs	Reuse Reduction Recycling
5Rs	Reduce, Reuse, Recycle, Recovery and Residual
ALUCAM	Aluminium Cameroon (Compagnie Camérounaise de l'Aluminium)
ARP	Authority for Regional Planning
BDCP	Bio-resource Development and Conservation Program
BEAC	Banque des États de L'Afrique Centrale (Bank of Central African States)
BMBF	Bundesministerium für Bildung und Forschung (German Federal Ministry of Education and Research)
BOD	Biological Oxygen Demand
BTU	Brandenburg Technical University, Cottbus
CAR	Central African Republic
CBC	Cameroon Baptist Convention
CBD	Convention on Biodiversity
CDC	Cameroon Development Corporation
CEC	Cation exchange capacity
CFU	Coliform Forming Units
CNN	Cable News Network
COD	Chemical Oxygen Demand
CVL	Cameroon Volcanic Line
EBA	Endemic Bird Species
EC	Electric Conductivity
EIA	Environmental Impact Assessment
EU	European Union
FCFA	Franc of the Financial Community of Africa
FEICOM	Fonds Spécial d'Equipement et d'Intervention Intercommunale (French: Special Council Support Fund)
GDP	Goss Domestic Production
GIS	Geographic Information System
GLP	Good Laboratory Practices

GPS	Global Positioning System
GRA	Govermnent Residential Area
HHW	Household Hazardous Waste
HYSACAM	Hygienne et Salubrité du Cameroun
ICMWM	Inter-Ministerial Commission for Municipal Waste Management in Cameroon
IDRC	International Disaster and Risk Conference
IMC	Inter Ministerial Committee
IPR	International Property Right
IR	Institute Responsible
ITCZ	Inter-Tropical Convergence Zone
IWM	Integrated Waste Management
LAR	Local authority responsible
LUC	Limbe Urban Council
MBC	Multiple Barrier Concept
MINDUH	Ministry of Urban Development and Housing
MINEFI	Ministry of Economy and Finance
MINEP	Ministry of Environmental and Nature Protection
MINET	Ministry of Environment and Technology
MINMITD	Ministry of Mines, Industries and Technological Development
MINPH	Ministry of Public Health
MINTAD	Ministry of Territorial Administration and Decentralisation
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
NA	Not available
NGO	Non-Governmental Organisation
NNW	North North West
OAPI	African Intellectual Property Organisation
ONADEF	Organisation Nationale pour le Développement Forestière
Pilcam	Battery Manufacturing Company Cameroon
QC	Quality Control

RASIM	Recommended Areas for Site Investigation Map
RCRA	Resource Conservation and Recovery Act
SAP	Structural Adjustment Programme
SNEC	Société Nationale des Eaux du Cameroun (National Water Supply Company Cameroon)
SONARA	Société Nationale de Raffinage (Cameroon Oil Rifinery)
SPG	Strategic Planning Guide
SS Quarters	Senior Service Quarters
SSW	South South West
TASi	Technical Instructions of Waste for Human Settlement
TDS	Total Dissolved Solids
TH	Total Hardness
TOC	Total Organic Carbon
UNEP	United Nations Environmental Programme
UPOV	Union for the Protection of New Variety of Plants
USRCRA	United States Resource Conservation and Recovery Act
WB	World Bank
WHO	World Health Organisation
WMO	World Meteorological Organisation

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Background to the Study

Today, many countries suffer from the depletion of natural resources as a result of population increase and industrialisation. Owing to these developments, it has become more urgent than ever before to take precautionary measures in view of repairing the already existing damages and to prevent expected (future) hazards. Resources to be protected include water, soil and air which suffer pollution from landfills, industrial sites and other areas used by man (Knödel et al, 2007).

Water is one of the most valuable natural resources, because it supplies both the animal and plant kingdoms with daily substances as well as provides highways for transportation (Wisler and Brater, 1959). Without water, no form of life will be possible. However, it can also be a source of destruction through floods and storms as it affects life, transports waste to soil (through groundwater percolation) and other water bodies; erodes and carries away many tons of fertile soil into the sea. Unfortunately, the current global increase in population has enhanced increased demand for water resources.

The availability of water varies from one point (zone) to the next, that is, it varies from the unlimited water supply in some mountain areas to nearly nothing in desert regions (Wisler and Brater, 1959). The earth holds about 300 000 000 m^3 of water beneath the land surface, on the surface, and in the atmosphere, which is in constant motion in what is referred to as the hydrologic cycle. The most important components of the hydrologic cycle are precipitation and run-off. Others include evaporation, infiltration, transpiration, percolation, groundwater recharge, interflow and groundwater discharge (Ward and Elliot, 1995).

Groundwater is a very important resource which is undergoing a lot of contamination and must be protected. This is water found beneath the ground surface and constitutes about 4% of water in the hydrologic cycle (Wanielista et al, 1997; Ward and Elliot, 1995). It is the most important source of drinking water in many parts of the world because it is believed to be the safest source of pure water; but it is very vulnerable to contamination. It is also believed that groundwater is an inexhaustible resource, but reality has proven it to show signs of scarcity (Wisler and Brater, 1959). Over-pumping of this resource encourages the infiltration of surface water which goes along with its pollutants (Botkin and Keller, 1995).

Groundwater is the main source of drinking water for more than 80% of the population in Germany. In rural areas, 85-90 percent of the residents obtain their drinking water from groundwater sources. Because of the importance to maintain the supply of good drinking water quality, groundwater therefore merits protection from contamination. The movement of contaminants through the soil to groundwater is dependent on many variables like the properties of the contaminants, soil conditions, the nature of the underlying substratum, its tectonic history as well as the prevailing climatic factors. A combination of these factors makes the likelihood of groundwater contamination a very site-specific science. A thorough understanding of these processes and variables is consequently critical for the effective management of potential groundwater contaminants.

Groundwater located anywhere near a landfill must be monitored because of the possibility of leachate formation and infiltration. Once a landfill site has been chosen, and before filling starts, groundwater monitoring should begin. Monitoring involves a periodic taking of water samples and gas from designed monitoring wells and this should go on as long as there is a probability of contamination. This procedure should continue even after the landfill is permanently closed and covered. This is because closed landfill sites are always used for other purposes, and any small depression can collect surface water that can infiltrate and produce leachate. Abandoned landfills should also undergo monitoring and proper maintenance in order to reduce its pollution potential (Botkin and Keller, 2003).

Industrial societies have important infrastructure like waste disposal (landfill), mining and industrial sites, which require suitable sites for construction. These sites are often difficult to obtain because of the need for political approval, which will only be easy if state-of-the-art methods are used to portray that barriers can prevent environmental contamination. Areas with both consolidated and unconsolidated rock are suitable sites for landfill construction (Knödel et al, 2007). More so, the disposal of waste is of great concern to those who are interested in building a sustainable future, because it squanders the earth’s resources - the more we throw away, the more minerals that must be mined and the more trees that must be cut. Moreover, it is clear that much waste is generated than the acceptable space that is available for permanent disposal (Botkin and Keller, 1995). Municipal Solid Waste (MSW-garbage like discarded paper, metal, leftover food and other items from homes, businesses, hospitals, airports, schools and stores in towns and cities) is the most generated waste worldwide (Chiras, 1998).

The problem is that most waste is transferred from one point to another without adequate management. For example, waste generated in urban areas when dumped in a landfill might produce methane (CH_4) and noxious liquids that cause air pollution, and could also leak and contaminate the surrounding areas and groundwater (Botkin and Keller, 1995). As a result, waste must be properly managed (that is, sorted, reused, recycled, reduced and treated) before final disposal in order to ensure public health and safety. In Germany, waste dumped in a municipal landfill should contain no more than 2% of organic matter. Waste disposal can be achieved through the following methods: on-site disposal, composting, incineration, open dumps and landfills.

Landfilling is the engineered deposit of waste onto or into land in such a way that pollution or harm to the environment is prevented, and through restoration, land provided which may be used for another purpose. The prevention of environmental harm requires effective control of waste degradation processes and effective landfill design, engineering and management (Westlake, 1995). Landfills can be divided into secure and sanitary landfills. Secure landfills are designed specifically for hazardous waste, while sanitary landfills are for municipal solid waste. Secure landfills are similar to sanitary landfills because they require multiple barriers and collection systems to ensure that leachate does not contaminate the soil and other resources (Botkin and Keller, 2003).

This study lays special emphasis on the construction of sanitary landfills because they are most appropriate for municipal solid waste disposal. A sanitary landfill according to Chiras, (1998) is defined as a solid waste disposal site where garbage is dumped and covered daily with a layer of soil to reduce rodents, insects and odour. He also goes further to say that this could be a natural or man-made depression into which solid wastes are dumped, compressed and covered daily with a layer of dirt. It is a method of solid waste disposal without creating a nuisance or hazard to public health and safety (Botkin and Keller, 2003).

In spite of the fact that sanitary landfills are generally unsustainable, they can be made more environmentally acceptable if they are located away from groundwater supplies and if toxic leachate is collected and treated, and methane gas captured (Chiras, 1998). The name sanitary landfill comes from the fact that the waste is covered. The compacted layer of a landfill performs the following functions:

- Restricts continued access to waste by insects, rodents and other animals
- Isolates the refuse, therefore minimising the amount of surface water percolating and gas escaping from the waste.

Groundwater contamination can also be reduced if the landfill is located away from streams, lakes and aquifers. Test wells dug around the landfill can be used to monitor and control the movement of pollutants away from waste sites. Special drainage systems together with careful landscaping can reduce water flow over the landfill surface and consequently the amount of water that penetrates and percolates the landfill. Impermeable clay caps and liners also reduce water infiltration and pollutant escape. Also, escaping contaminants/pollutants can be collected through specially built drainage systems for detoxification (Chiras, 1998).

Global world statistics indicate that about 1.3 billion people lack access to adequate supply of safe water, while 2 billion people do not have access to adequate sanitation (UNEP et al, 1997; CNN News, 2006). However, it is important to note that the most important hazard from a sanitary landfill is ground and surface water contamination. Groundwater will be contaminated if it gets in contact with percolating water called leachate, which is any noxious mineralised liquid that is capable of transporting bacterial pollutants. It is produced when water (precipitation, surface water infiltration, water percolating from adjacent land and contact between groundwater and landfill) infiltrates through waste material and becomes contaminated and/or polluted (Botkin and Keller, 1995; 2003). Important pollutants found in leachate include BOD, COD, Fe, Mn, chloride, nitrate, hardness and trace elements (Todd and Mays, 2005).

However, the nature and strength of leachate is determined by the waste composition, the amount of percolating water and the length of time that percolating water is in contact with waste (Botkin and Keller, 2003). This is due to the fact that the moisture content of ordinarily mixed waste is less than waste of field capacity (Todd and Mays, 2005).Leachate from landfill and waste sites can be minimised if water is kept away from the fill. Landfill leachate could be controlled and prevented from contaminating groundwater if the landfill is properly located, constructed, managed and monitored.

There is a serious problem of waste disposal in developing countries, particularly in Africa. In Cameroon, for example, waste disposal is a serious problem as most towns and cities practise open dumping which is not healthy. There is actually no set system for the collection of waste. Medical and household wastes, for example, are jointly disposed off in many Cameroonian towns. However, there are laws that govern waste management, even though these are hardly implemented. For example, Law No. 96/12, Environmental Management Law states that any person producing waste shall eliminate or recycle it and is required to inform the public of the effects of its production, elimination or recycling on the environment and public health. Also, Law 89/027 forbids the introduction, production, storage, transportation and disposal of hazardous waste in Cameroon. Nonetheless, it makes flexible provision for projects that generate hazardous waste. The owner of such a project is required to declare the volume and nature of waste produced, as well as he should ensure its elimination without danger to man and his environment. The highest penalty in case of infraction is the death penalty (Geovic Cameroon, 2007). However, these regulations are unfortunately not implemented in most Cameroonian towns.

In Cameroon, like many African countries, waste management is poorly practised. Results of a research carried out by Manga et al, (2007) indicate that solid waste management services are rudimentary; they essentially collect and dump waste without proper management methods. This form of management is due to factors like inadequate financial resources, low levels of law enforcement and poor governance, lack of human resource, only to name a few. Moreover, current regulations do not adequately address waste handling or disposal and there exist an inefficient implementation of waste management policies and documentation due to the devolved responsibilities between several governmental agencies and the local councils (Manga et al, 2007). This scarcity of literature is inadequate for the proper functioning of waste management units. In effect, waste management in Limbe is inefficient in hazard minimisation since sustained efforts have not been made in the direction of waste collection, transportation, treatment and final disposal.

The case of the Limbe Urban Council (LUC) has thus been used to emphasise some of the waste management related problems in Cameroon. Literature on waste management (collection, transportation, treatment, reuse, recycling, recovery and disposal) in Cameroon is often very scarce and/or non-existent. This hampers an evaluation of the existing situation and a comparison with other countries.

The sustainable management of solid waste systems is absolutely necessary in order to minimise environmental and public health risks worldwide (Manga et al, 2007). The balance between the specific components of this system in delivering sustainable waste management are already well understood and established in most developed countries, unlike in some developing countries like Cameroon. Waste management could be efficient through the involvement of all stakeholders, that is, the waste generators, waste processors, formal and informal sectors, financial institutions and private initiatives such as non-governmental and community based organisations (Manga et al, 2007).

1.2 Presentation of the Study Area

1.2.1 An Overview of Cameroon

The Republic of Cameroon which is found in the Central African Region (2°-13°N and 8°-16°E) is situated on the extreme north-eastern end of the Gulf of Guinea. This makes it exposed to a very large variety of natural hazards, some of which are associated with volcanic activity. Such hazards are concentrated around the Cameroon Volcanic Line (CVL), especially around Mt. Cameroon, which is associated with effusive and explosive types of activity (Zogning et al, 2009). Cameroon also shares boundaries with the Atlantic Ocean, Nigeria, Central African Republic, Equatorial Guinea, Gabon and Congo Brazzaville (Fig. 1). Cameroon is actually located between Central and West Africa, but belongs to the Central African Union. It has a surface area of 469,440km² and population of about 20 million inhabitants (Manga et al, 2007; Eyong and Mbuagbo, 2003).

The country is divided into ten different Regions (formerly called Provinces) headed by Governors. These Regions are further divided into Divisions and Sub-Divisions administered by presidentially appointed administrators. The main topographical regions in Cameroon include:

1. the low coastal plain, which is covered by the equatorial rainforests in the south,
2. the mountain forests, with peak on the Mt. Cameroon in the west,
3. the plateau, which rises to the Adamawa Mountains in the north and
4. the rolling savannah slopes that graduate down to the marshland, which surround the Lake Chad Basin situated towards the north of the Adamawa Mountain range.

The climate of Cameroon results from the combined convergence effects of the tropical oceanic low-pressure zone and the inter-tropical front within Africa. Two distinct seasons are witnessed in the country: a long rainy season normally up to 7 month (March-October) and an extremely short dry season (November-February). The south-westerly monsoon winds are the most predominant with wind speed reaching 18m/sec (Eyong and Mbuagbo, 2003). The duration of the rainy season and the amount of rainfall decreases from south to the northern part of Cameroon. Three major climatic zones can be identified in the country. These are:

1. The Equatorial zone in the south, which is characterized by abundant rainfall (about seven months) and forest vegetation;
2. The Sudanian zone in the north-central part of the country, which is characterized by a combination of grasslands and scanty forest vegetation;
3. The Sudano-Sahelian zone in the north, which is characterized mainly by semi-arid grassland vegetation (Asong, 2010).

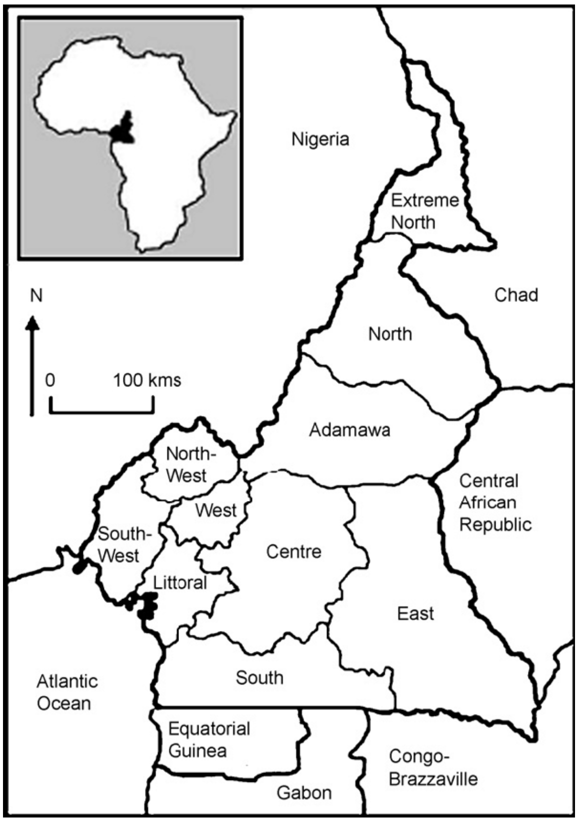


Figure 1: Map of Cameroon showing its regional and international boundaries

Source: Manga et al, 2007

1.2.2 An Overview of Limbe

Limbe, located along the rocky coast of Cameroon, is found in the South West Region. It is the capital of Fako Division and Limbe Sub-division (Figs. 2 and 3), and is made up of more than 25 villages (Buh, 2009). It is a coastal city found along the Gulf of Guinea located between longitude 9° 13' and latitude 4° 1' north of the equator (Awemo, 2000; Awum et al, 2001). It has a total area of about 674km^2 with an estimated population of about 120.000 inhabitants. The annual growth rate is at about 2.9% compared to the national rate of 4.1% with a total of 18,508 houses according to statistics of 2009 (Asong, 2010; Awum et al, 2001; Manga et al, 2007; World Bank, 2002; Zogning et al, 2009). It is a City Council since January 2008 with three sub-divisional councils, called Limbe I (POH), Limbe II (Munkundange Council) and Limbe III (Bimbia Council) each headed by a Mayor and 2 deputies (Asong; 2010).

It is found at the foot of Mount Cameroon and Mount Etindi. Mt Cameroon is a vast volcanic massif some 50km long and 35km wide with a height of 4100m and an area of about 3000km^2 (Zogning et al, 2009). It is the highest mountain in West Africa, with Mt. Etinde commonly referred to as small Mt. Cameroon, near it and with a height of 1713m. Hence, the soils of Limbe are of volcanic origin and Limbe lies along the Cameroon Volcanic Line (CVL). Western Cameroon and Fako Division in particular, lie on the junction of the West African and Congo continental plates. Stresses and instability in this area have resulted in the formation of a series of volcanoes of which Mt. Cameroon is the largest. Volcanic activity began in the Upper Cretaceous, about 100 million years ago (Stuart et al, 1986). Mt. Cameroon is an active Hawaiian-type volcano formed of fairly mobile basaltic lavas erupting from fissures on its flanks rather than from a central crater. Mt. Etindi, which is a subsidiary peak on the southern side of Mt. Cameroon, is formed of Tertiary basaltic lavas.

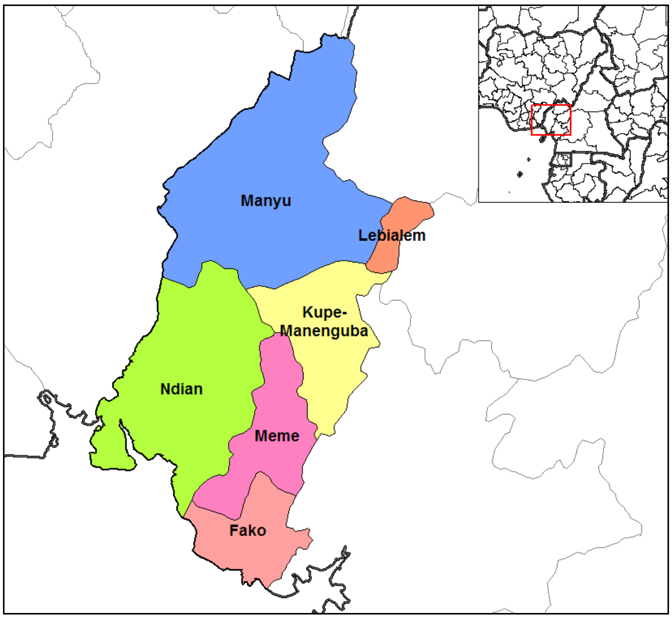


Figure 2: Map of the divisions of South West Region in Cameroon

Source: http://en.wikipedia.org/wiki/File:Southwest_Cameroon_divisions.png

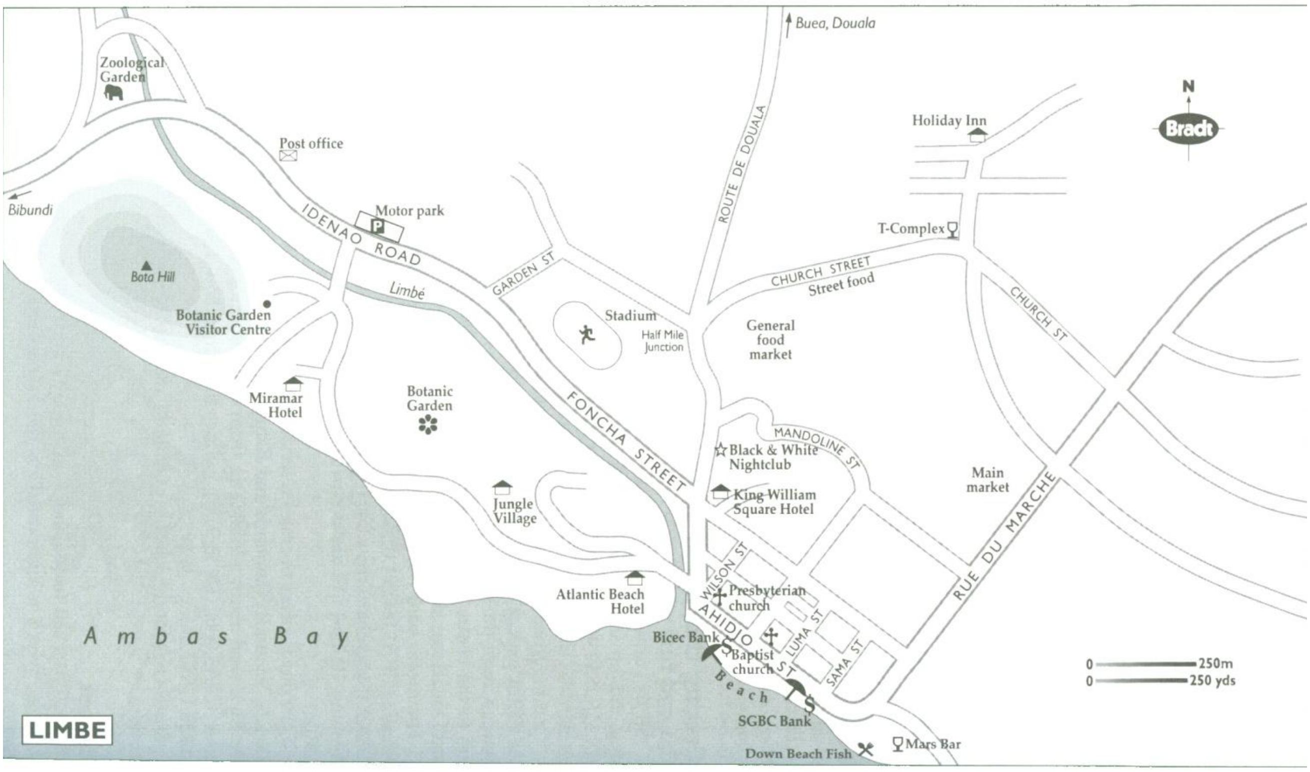


Figure 3: Map of Limbe

Source: http://mappery.com/city-maps-Limbe

Mount Cameroon is a stratovolcano-tectonic massive made dominantly of basaltic rock above a basement of Precambrian metamorphic rocks that is covered with Cretaceous to Quaternary sediments (Zogning et al, 2009). It is relatively very active, with eruption from fissures on the flanks and the summit of the mountain. These eruptions have been recorded to have large flows of lava. The earliest reported eruption of Mt Cameroon dates as far back as 2.500 BP, witnessed by the Carthaginian explorer, Hanno. Eruptive activity on the mountain was reported only from the early 19th Century, where a total of seven eruptions were dated: 1815, 1835, 1838, 1839, 1852, 1865-66 and 1868. Seven other eruptive activities occurred in the 20th Century, in 1909, 1922, 1954, 1959, 1982, 1999 and 2000 (Lambi et al, 2001; Zogning et al, 2009).

1.2.2.1 Geology of Limbe

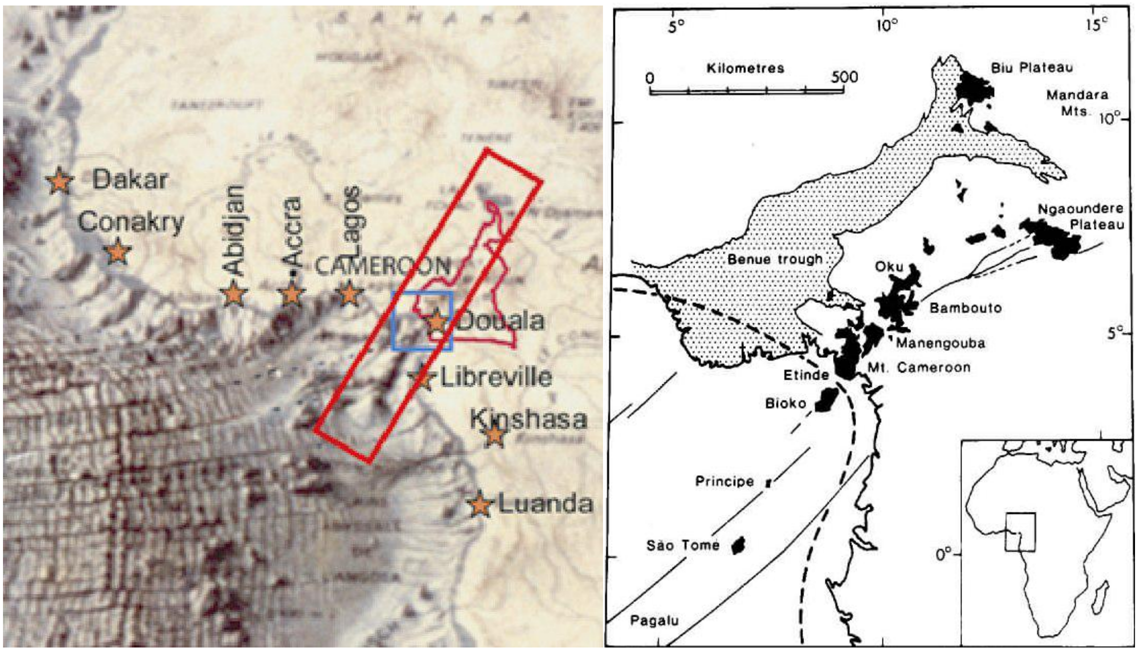


Figure 4: A) Geographic location of Cameroon showing Cameroon Volcanic Line. B) Geological map of part of West Africa showing the Cameroon volcanic line of rocks (black) and the Benue trough (stippled). The boundary between continental and oceanic crust are shown as bold broken lines.

Source: Zogning et al, 2009

Limbe is found in an active and dynamic coastal zone that is characterized by a variety of natural hazards like, geological, geomorphological, geophysical and climatic hazards (Kometa, 2010; Zogning et al, 2009). It also belongs to the Cameroon Volcanic Line (CVL), which is a 1600km y-shaped chain of Tertiary to Recent volcanic rocks (Ubangoh et al, 1998; Zogning et al, 2009). The CVL is a South-West North-East volcano-tectonic trend that straddles the continental margin. It extends some 900km across Cameroon from Biu and Adamawa Plateaus to Mt. Cameroon, and Equatorial Guinea in the Gulf of Guinea. It continues seaward for about 700km from the coast through the Atlantic Islands of Principe, São Tomé and Pagalu (Ubangoh et al, 1998). In Figure 4, the red rectangle indicates the CVL, the blue square indicates the Mount Cameroon area and the pink line indicates the border of Cameroon (Zogning et al, 2009).

The fact that Limbe creates a link between the continental segment of the CVL and the ocean explains why it is confined between surrounding hills and the Atlantic Ocean. These hills are made up of scoriaceous cones that have been deeply weathered making them unstable and highly vulnerable to slope movement. This further explains its vulnerability to floods, earthquakes, landslides, mudflows and other natural hazards. Hence, human settlement on such an area is dangerous. Table 1 below would enhance a better understanding of the level of natural risks associated with Limbe. Unfortunately, food crop cultivation, for example, takes place in 30km^2 of very high hazard zones, that is, Limbe-Mabeta essentially and 50km^2 of high hazard zone, that is, the slopes of Tamben-Misellele. Data in the Table were obtained through the consideration of different stake values, which were quantified, such that the number of inhabitants per locality, the level of importance relative to crisis management, the evaluation of the unit cost of various infrastructures, the values of agricultural production and others, could enable the establishment of a hierarchy as a function of the different periods of crisis like out of crisis, pre-crisis, crisis and recuperation phase (Zogning et al, 2009).

Table 1: Intensity of threats in the Limbe Council (area in km²)

	INTENSITY OF THREAT				
Hazard	**weak**	**Moderate**	**High**	**Very High**	**Total**
Lava		37.28			37.28
Fallback	170.41				170.41
Gas	170.41				170.41
Seismic		170.41			170.41
Lahar			6.29		6.29
Tidal wave	1.14	0.84	0.91	0.76	3.65
Inundation	8.31	1.17	10.11	9.53	29.12
Landslide	4.15	10.79	11.53	9.40	35.87
Deposit			22.43		22.43
Rockfall	4.26	7.24	8.40	8.22	28.12
Total	**358.68**	**227.73**	**59.67**	**27.91**	**673.99**

Source: Zogning et al, 2009

Limbe has experienced intermittent Tertiary volcanic activity in recent times. There are igneous (basalt and pyroclastic materials) and sedimentary (mud rock or mudstone and alluvial deposits) rocks found in this area. Sixty-six percent of the area is made of basalts (partially affected by erosion), with scattered portions of sedimentary rocks and pyroclastic material.

- Basalts are of three types; vesicular (fine-grained and compacted with vesicles), fine-grained (highly compacted with no traces of weathering) and porphyritic basalts. The fine-grained basalts result from fast cooling of hot magma. Porphyritic basalts are either Olivine crystals (hardly more than 1mm in size) or Augite (more abundant form in the Limbe area) in origin. Basalts weather to dark red soils which form the best arable land (Onege, 1998).

- Pyroclasts are made up of fragmented volcanic material blown into the atmosphere by explosive activity. They come from volcanoes with more viscous lava and can be consolidated or unconsolidated. Unconsolidated pyroclasts include: volcanic bombs (lava that solidified before reaching the ground), pumice and scoria (These are denser than pumice and almost solidified when they reach the ground. They flatten out when they fall to the ground because they are soft).

- Mudstone/Mudrock is fine-grained sedimentary rock with clay or mud as its original constituents. It has a grain size up to 0.0625mm and the individual grains are too small to be distinguished without a microscope. This is deposited on basalts before pyroclasts. It is brittle and dark in colour, and contains a certain amount of organic material.

- Alluvial deposits are loose unconsolidated sediments which can be re-shaped and transported by water. They consist mainly of sand, silt and organic material.

Plate 1: Illustration of layered strata of pyroclastic and scoriaceous hills and cones

This study focuses on the management of waste and groundwater contamination in Limbe, which is the economic capital of the South West Region of Cameroon. Economically, it is dominated by growing tourism, assorted commercial and industrial activities, and plantation agriculture. Limbe is located near two important mountains in Cameroon, Mounts Cameroon (in Buea) and Etindi (in Limbe). The central mountain dome consists of a mass of volcanic rocks surrounded by a rim of sedimentary deposits. The rocks may be divided into three main groups, namely, sedimentary deposits, Quaternary volcanic rocks and basement complex rocks. The heart of the region consists of a vast thickness of volcanic rocks-lavas, fine-grained ashes and coarse conglomerates which were poured out during long periods of volcanic activity in the Holocene and Pliocene deposition, and sedimentary processes. These include layers of volcanic materials representing mudflows among the volcanic materials. The mountains (Mounts Cameroon and Etindi) are tectonic in origin and are surrounded at the foot zone by pyroclastic and scoriaceous hills or cones as in Plate 1 and Figure 5.

The basement consists of Precambrian gneisses, schist, quartzite and some kinds of plutonic rocks. Folded axes and faults in the basement rocks generally run from SSW to NNW. These rocks make up a low relief erosion surface lying about 500m above sea level. Reddish soils extensively cover the basement rocks except at the bottom of valleys (Awum et al, 2001). The surface is covered with red or reddish brown soil.

In Limbe, sedimentary rocks of Cretaceous and Tertiary periods exist on the coastal district. They consist of sand and gravel with mud beds and pyroclastic materials. Moreover, this town is characterized by an irregular relief of high and lowland. This irregular lowland relief erosion surface is less than 100m in height and agrees with the distribution of the sedimentary formation (Asong, 2010; Kometa, 2010).

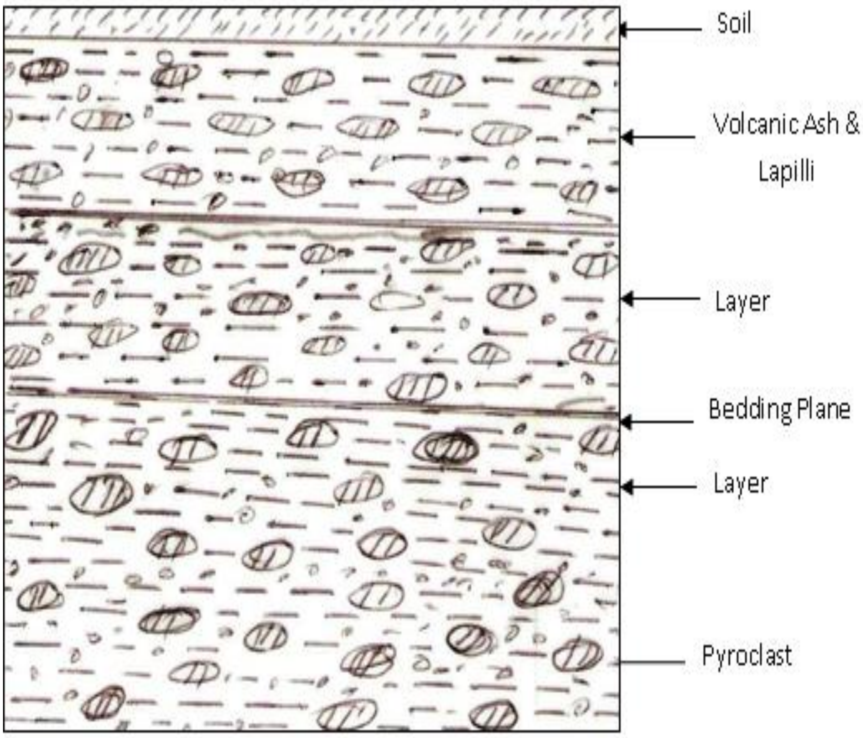


Figure 5: Generalized profile of a typical scoriaceous cone showing the layered strata of the cones. Layering in some cases is not always visibly obvious in some pyroclastic cones

A further description is that the town has a basin-like structure with a couple of topographic elevations. However, its geomorphologic setting is defined by bays and headlands, and as a result, it has a low lying land surface that grades into a hilly peripheral setting landwards. Most of the low-lying areas are characterized by episodes of some degree of floods and mudslides during the intense rainy season (June, July and August) coupled with the fact that the water table is just a few meters below the surface. This also accounts for the swamps and wetlands seen in this area (Asong, 2010; Awum et al, 2001). Apart from the torrential rainfall, low-lying bedrocks are overlain by pyroclastic deposits with high susceptibility to coastal erosion, prevailing winds and powerful sea waves, hence the floods, swamps and wetlands

(Asong, 2010; Kometa, 2010; Zogning et al, 2009). The drainage system in Limbe is very poor and also enhances the occurrence of these hazards.

The land use map of Limbe (Figure 6) shows the different types of land activities that take place in Limbe. The red portion shows the areas used by CDC as plantations of banana and palm, the dark green patches are mangrove forests, the cream patches, especially surrounded by the mangroves are sub-montane forests which have partially been undisturbed; and the bluish-green patches represent areas used for industrial activities.

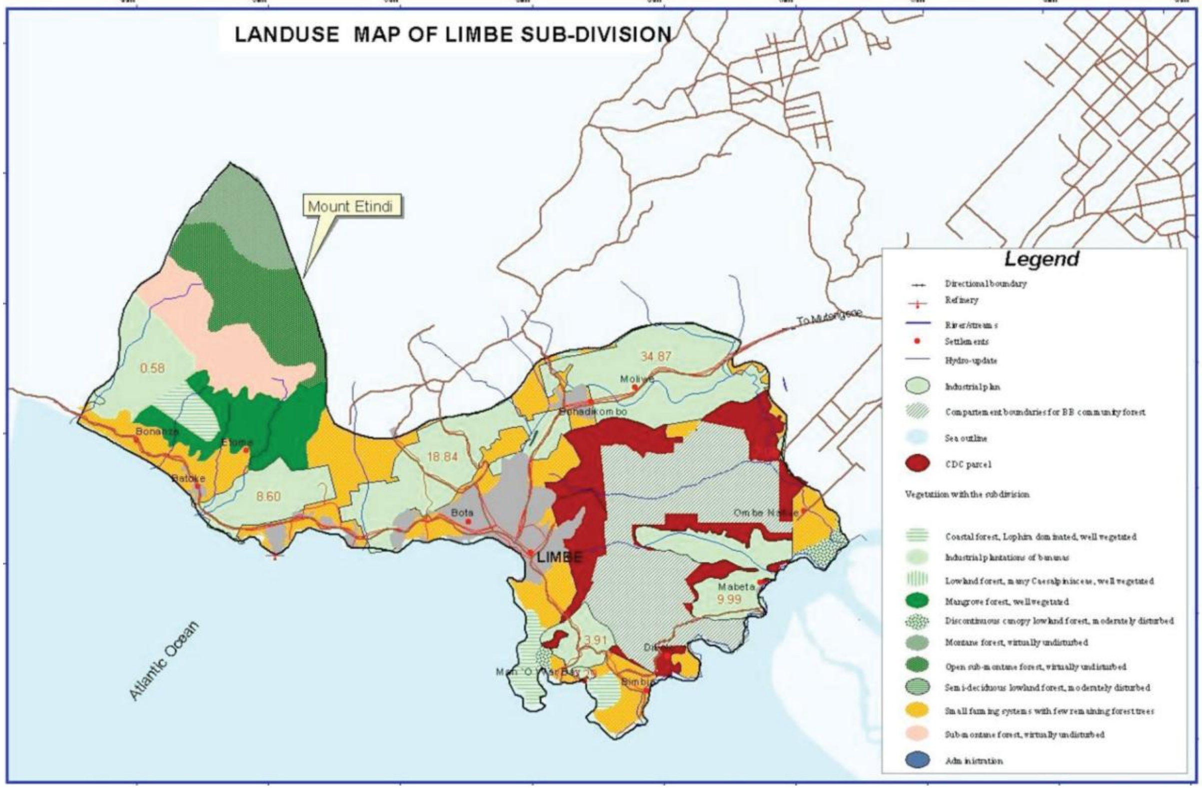


Figure 6: Land use map of Limbe

Source: Buh, 2009

1.2.2.2 Climate of Limbe

Limbe is a coastal town near the Atlantic Ocean. It experiences a tropical climate with a rainy and dry season. Intermittent torrential rains lead to the overflow of small streams within the city and trigger several voluminous torrents from highland areas towards the coast. In Limbe and the Mount Cameroon Region, the CDC (Cameroon Development Corporation) has maintained an extensive network of meteorological stations throughout their plantations. Until 1998, up to 40 active stations existed from which they could obtain climatic data. They also have geographical data of the areas where these stations are found (Table 2).

Table 2: Key geographical variables around Mount Cameroon

Site	Altitude (m)	Distance from coast (km)	Direction from coast
Mokoko	200	21	East

Idenau	40	1	On the coast
Debundscha	20	0.5	On the coast
Mokundange	40	0.5	On the coast
Mabeta	20	20	In the mangroove creeks
Tole	700	25	North-East
Molyko	400	36	North-East
Mpundu	40	44	North-East

Source: Fraser et al, 1998

Table 3: Climatic variables, form of data supplied by CDC, basic values calculated and recording equipment used

Variable	**Form of data**	**Statistics appended**	**Recording equipment**
Rainfall (mm)	Monthly total	Mean, max and min	127mm diameter rainguage
Rainfall (days)	Monthly total	Mean, max and min	
Air temperature (°C)	Max monthly	Mean, max and min	Thermometer inside a Stephenson screen
Air temperature (°C)	Min monthly	Mean, max and min	
Sunshine (hours)	Monthly total	Mean, max and min	Campbell Strokes Pattern Mark 3 sunshine recorder mounted on a 1m high concrete pillar
Sunshine (days)	Monthly total	Mean, max and min	

Source: Fraser et al, 1998

The climatic variables used by CDC are seen in Table 3. The data for the climate in Limbe (Mabeta and Mokundange) include daily up to yearly data. These climatic data are required in waste site location. Data obtained imply that Limbe is under continental winds from the north-east and maritime winds from the south-west at different times of the year (Fraser et al, 1998). Between November and April, there is the Harmattan which results in a dusty dry season with visibility of less than 1km. In April or May the ITCZ (Inter-Tropical Convergence Zone) moving northwards, draws pressure system and south-westerly moisture laden winds over the country. This breaks the dry season and brings rains, which are accompanied by frequent high wind and intense storms. Rainfall continues until September, but not as heavy as in June, July and sometimes August. Rainfall in Limbe varies slightly from high rainfall in areas near Debunscha and relatively low rainfall in the Mabeta area (Tables 4 & 5). The temperature in Limbe ranges between 10°C, in the cold season and 32°C or higher, in the dry season. The sun is always high in the sky like in other equatorial regions which explain the little changes in the number of daylight hours (Fraser et al, 1998).

Table 4: Summary of monthly rainfall, temperature and sunshine in Mokundange and Mabeta, Limbe

Rainfall (mm)

Mokundange	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	55	91	163	189	287	801	1089	1127	724	323	115	40
SD	62.5	69.5	73.5	81.0	174.1	352.8	578.2	429.8	396.0	106.8	55.6	34.0
Max	340	322	294	388	759	1515	2137	2266	2490	474	274	126
Min	0	2	18	92	109	203	166	456	284	145	18	0
N	23	23	23	23	23	23	23	24	24	24	24	24
Mabeta												
Mean	40.58	69.25	18,9	214.2	324.6	656.3	1022	899.8	455.1	293.8	151.7	46.13
SD	17,7	63.02	199.8	95.12	145	254	319.8	453.8	213.6	96.42	102.9	43.58
Max	394.7	196	983.3	571	666.9	1162	1414	2176	1260	556.2	474	167.6
Min	0	0	32.5	94	66.6	221.8	185.3	174.1	167	171.2	27.1	0
N	24	24	24	24	24	24	24	24	24	24	24	24

Rainfall (days)

Mokundange	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	4,7	7,9	13,8	13,6	15,7	21,8	25,5	26,7	25,2	20,8	10,7	3,5
SD	2,73	4,15	3,6	2,7	3,6	3,9	2,8	5,7	2,8	2,9	2,8	2,3
Max	11	14	19	20	26	28	30	31	29	28	16	8
Min	0	1	7	8	11	13	18	8	17	14	5	0
N	18	18	18	18	19	19	19	19	19	19	19	19
Mabeta												
Mean	1,6	3,5	8,5	10,6	14,3	17,6	22,1	23,1	16,8	16,2	6,6	2,4
SD	1,9	2,4	2,9	3,2	4,4	5,4	6,3	5,8	4,6	4,7	2,4	1,9
Max	6	8	13	16	23	23	29	30	24	25	11	5
Min	0	0	3	4	5	4	8	8	4	3	1	0
N	15	15	15	15	15	15	16	16	16	16	16	16

Maximum temperature (°C)

Mokundange	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	30,8	31,7	31	30,8	30,6	29,4	28,3	27,9	28,5	29	29,7	30,4
SD	0.6	0.9	0.7	0.7	0.6	0.9	1,2	1,4	1,4	0.7	0.8	0.9
Max	32	33	32	32	31	32	31	31	32	30	31	31
Min	30	30	30	30	29	28	27	26	27	28	28	28
N	13	14	14	14	15	15	15	15	15	14	14	14

Mabeta												
Mean	30,8	31,1	30,5	30	30,1	29,2	28,6	27,7	28,1	28,4	29,3	30,1
SD	0.6	0.6	1,1	1,5	0.9	0.8	1,4	0.9	0.9	1	1,1	0.5
Max	32	32	32	32	31	30	30	29	30	30	31	31
Min	30	30	28	28	28	28	26	27	27	27	27	29
N	8	7	8	8	9	9	9	9	9	9	9	9
Minimum temperature (°C)												
Mokundange	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Mean	18,8	18,5	18,9	18,8	18,4	17,7	17,8	17,5	17,3	17,1	17,6	17,9
SD	4,2	3,3	3,2	3,4	3,2	3,3	4,1	3,7	3,6	3,5	3,9	3,6
Max	26	24	23	23	23	22	26	22	22	22	23	23
Min	13	14	15	14	14	13	13	13	13	13	13	13
N	10	9	10	10	10	10	11	11	11	10	10	10
Mabeta												
Mean	21,9	22,9	22,8	22,8	22,3	21,8	21,4	22,2	21,7	21,6	22,2	22,2
SD	2,6	2,6	2,1	1,9	2,5	2,4	2,7	2	2,2	1,8	2,1	1,4
Max	25	25	25	24	24	24	24	24	24	23	24	24
Min	18	18	19	19	18	18	17	17	17	18	18	20
N	10	9	10	10	10	10	11	11	11	10	10	10
Sunshine (days)												
Mokundange	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Mean	29	26,8	28	28,2	27,6	25,3	23,3	19,1	24,8	24	26	29
SD	2,6	0,7	3,8	1,3	4,3	4,4	4,8	7,4	2,1	4,6	1,7	1,6
Max	31	28	31	30	31	29	28	27	27	28	28	31
Min	24	26	23	27	19	17	14	5	22	17	24	27
N	6	6	6	5	6	6	6	6	6	6	6	4
Mabeta												
Mean	28	25,3	26,6	27,8	28	24,2	17,5	15,3	21,6	23	24	27
SD	2,2	1,89	2,8	2,2	2,5	4	6,7	7,9	3,2	9,7	7	1,5
Max	31	27	30	30	31	28	27	26	25	31	29	29
Min	25	23	22	24	25	19	9	5	16	4	10	25
N	6	6	6	6	6	5	6	6	6	6	6	5
Sunshine (hours)												

Mokundange	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	172.2	166.7	149.7	160	151.7	121.2	80.3	63.5	89.3	110.2	153	168.1
SD	26,6	24,2	31,9	23,7	31,1	23,4	34,8	38,2	24,8	21,6	249	40,6
Max	219.9	193.9	204.5	186.2	177.7	149.1	145.3	112.1	123.4	153.4	194.2	228.9
Min	142.5	117.2	88.7	116.6	82	70,5	24,6	2,5	46,1	85,5	97,2	101,8
N	9	9	9	8	9	9	10	10	10	11	11	10
Mabeta												
Mean	159.7	164.4	143.3	160.8	176.9	129.3	81.1	49.4	90.0	108	136.7	152.9
SD	31.4	26,6	22,6	34,7	22,5	29,1	47,7	30,4	29,2	32,7	39,6	43,4
Max	210.1	209.8	174.9	220.7	200	173.1	151.1	99.2	140.9	148.7	180.6	205.6
Min	100.7	128.2	105.6	106.4	132	76.2	18,6	6,3	43,5	32	70,6	57,6
N	10	10	10	10	9	9	10	10	10	11	11	10

Source: Fraser et al, 1998

Table 5: Annual monthly totals of rainfall (mm)

Mabeta	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970	22,8	15,1	69,1	323,8	240,1	1162	1368	536,8	382,6	389,8	176,4	49,8
1971	36,4	29	113,4	167,4	66,6	636,6	1146	613,5	398,9	196,1	56,8	81,8
1972	40,8	31,8	65,8	312,7	292,6	912,7	1299	707	339,2	203,4	42	22,4
1973	33,6	184,8	249,5	247,6	248,3	477,7	524,4	700,6	252,6	448,5	85	62
1974	16,8	165	265,2	154,2	322,6	601,6	758,4	2176	414,7	246,2	474	0
1975	15,4	23,8	254,2	179,2	192,4	349	906,8	1172	451,6	390,6	231,8	67
1976	5,4	124,4	42,2	218,9	312,4	637,7	863	357,6	313,6	171,2	217,8	67
1977	31,8	36,6	49,4	241,4	214,2	1079	1331	646,8	184,4	214,4	27,1	7,8
1978	5,3	163,2	495,8	571	580,8	378,8	500,4	800,4	258,6	229,6	45,8	9,2
1979	4	5,2	124,5	181,8	102,2	605,7	854	760,6	629,6	294,2	184,2	100,1
1980	61,5	24,4	105,1	125,1	330,3	881,5	1269	1338	450,6	396,4	108,6	0
1981	0,8	20,3	983,3	212,3	479	599,9	1177	885,9	497,4	348,2	115,4	93,8
1982	427,7	67,5	141	258,6	522	727,6	996,6	562,4	390,6	239,1	35,2	5,5
1983	0	0	64,4	121,6	666,9	883,8	1044	791,8	480,2	237,8	289,7	111,7
1984	0	109,3	245,3	166,4	200,2	221,8	185,3	174,1	167	325,6	83,1	50
1985	46,5	51,5	172,1	234,6	318,8	340,1	565,8	856,7	355,8	282,1	150,9	0
1986	0	21,1	196,9	124,8	297,1	351,9	937,6	429,9	580,6	386,2	225,2	0
1987	6,5	70,8	177,1	154,7	334,9	261,4	1091	1227	298,7	235,9	178,2	79,4
1988	0	55,2	79,6	136,5	396,1	450,2	854,1	360,8	529,3	266,3	105,3	167,6

1989	0	0	40,9	216,5	197,3	553,8	1136	1378	492,3	277,6	198,5	43,5
1990	2	70,8	215,7	196,3	411,2	768	1288	1527	463	341,6	241,8	71,4
1991	15,7	196	32,5	270,2	432,8	757,3	862,8	1026	517,1	253	196	46,8
1992	18,2	14,5	257,9	135,6	437,2	741,3	1414	1345	1260	556,2	143,2	6,2
1993	394,7											

Source**:** Fraser et al, 1998

1.3 Statement of the Problem

In spite of the fact that Limbe has been the cleanest town in the South West Region (SWR), there are still lots of problems in managing the waste generated by the inhabitants (Awemo, 2000). Until July 2006, waste generated in Limbe was managed by the Limbe Urban Council (LUC). Waste was collected and dumped in an open area and later on burnt to create more space for further disposal. The waste and surrounding area smelt and so attracted insects and pests.

In July 2006, waste management in Limbe was handed over to HYSACAM (Hygienne et Salubrité du Cameroun), a French waste management company. Waste management has improved in the last few years; but a lot still has to be done. HYSACAM undertakes a slightly better form of waste disposal. They collect; dump and burn waste more frequently than LUC and have also cleaned up many other unofficial open dumps in the town. As a result, this study investigates the effectiveness of HYSACAM in the direction of waste disposal methods, waste treatment before disposal, groundwater monitoring (management) and future plans.

Both LUC and HYSACAM used waste collection trucks to carry waste and the frequency of waste collection depended on the accessibility of the area by the truck. A waste collection programme/schedule was made in each case. Waste collection ranged from up to thrice a week in areas with higher living standards like, the Government Residential Area (GRA) to once a month in the slums inhabited by the poor. Waste collected is not sorted before disposal. This implies that hospital, household, battery; office and market wastes were mixed and disposed of in the main dumpsite. The only difference is that HYSACAM collects waste more frequently than LUC, but this is still not efficient according to the inhabitants of Limbe. This inefficiency in waste collection is due to the following reasons:

- Poor accessibility to waste collection points due to bad roads
- The constant breakdown of the collection trucks which require repairs
- Insufficient number of workers who sometimes fall ill due to improper medical health care.
- Too much work for the time allocated for waste collection

The infrequent collection of waste leads to waste overflowing and littering the big LUC waste bins.

Also, workers of both LUC and HYSACAM complained bitterly about the poor treatment they received from employers; they were given old cars which often break down; they have low wages and inappropriate clothing; they received poor health attention and they were overburdened with work, and all these contributed to their inefficiency in waste collection. Workers had to use shovels and brooms to collect littered waste in some places. This was very time-consuming and no one gave them attention and information on how to ease waste collection of the waste.

This method of disposal which has been practised in Limbe so far is considered to be very poor. To add to this, the disposal site is not properly located. Many people live around the main dump site at Mokunda (Karata). There are farms of plantains (*Musa paradisiaca normalis)*, oil palm (*Elias guineensis*), cocoa and coffee around this area. The people who live around here have food crop farms. These people have also dug wells from which they fetch water for drinking, cooking and washing. The most serious problem here is that these people are not even aware of the probability of groundwater contamination. Mosquitoes, as well as other insects and pests breed here as a result of the open dumping method used in the area.

Nevertheless, some people in Limbe (to a small extent) already practise sustainable techniques of waste management such as composting food waste, using leftover food to feed animals, reusing plastic and metal containers, burning papers and using cleared grass and leaves as manure on farmlands. This somehow already helps to reduce the waste that should be managed by the council. However, some of this waste includes clinical and household hazardous waste like paint, ink and detergents, which could seriously affect soil and groundwater.

The above methods of waste disposal practised in Limbe are not monitored, documented and controlled and this could possibly lead to soil, groundwater and air contamination. The source and degree of contamination cannot be estimated or known because there is no knowledge of the types and proportions of waste disposed of in this area. There is also no monitoring of soil and groundwater, and HYSACAM and LUC have no unit that should control the dumping of waste in this area. Contamination is also influenced by the method of disposal, high rainfall (rainy season) on disposed waste and the possibility of leachate infiltration.

1.4 Hypotheses of the Study

In order to address the issues raised in the problem statement, the following research hypotheses have been adopted:

1. The vulnerability of groundwater contamination is not a major consideration in the location of waste sites in Limbe.

2. The inappropriate method of waste disposal in Limbe enhances the contamination of groundwater.

3. Groundwater contamination in Limbe is enhanced by other factors such as soil and waste types, barrier system, precipitation, surface water, and the level of the water table.

4. Insufficient knowledge of waste management, limited equipment, managerial incompetence, and limited human and financial resources impede the continuous monitoring of waste sites for groundwater contamination or other environmental hazards.

5. The population around waste sites is more susceptible to water related diseases.

1.5 Objectives of the Study

The objectives of the study include:

1. To assess the degree to which Limbe waste sites conform to prescribed standards of waste site location, and groundwater management around waste sites.

2. To investigate the factors responsible, and the degree of susceptibility of groundwater to contamination from waste sites.

3. To evaluate the extent to which past and present municipal solid waste management practices minimise or enhance groundwater contamination.

4. To suggest possible methods (techniques) by which the existing situation can be improved upon.

CHAPTER TWO: METHODOLOGY

2.1: General Review

Data for this study were obtained through a careful examination of both secondary and primary sources. Secondary sources of data collection included books, journal articles, specialized environmental and waste management magazines, the Cameroon national environment and forest policy, other legal documents (decrees) relating to solid waste management in the country, Cameroon national and local Newspapers, Tabloids and Internet sources. The Cameroon Legislation regulating the use of the environment and forest resources was consulted as well as the recent EIA law in Cameroon. This provided background information that enabled the construction of a conceptual model of solid waste management in Limbe.

Meanwhile, primary sources that were used for the purpose of first hand information in the study included:

- Visits to the waste sites to confirm types of waste, method of waste disposal, residential area, farms and plantations around waste sites.
- Structured personal and group interviews were conducted with local people and workers of LUC and HYSACAM, as well as stakeholders in various sectors like hygiene and sanitation and urban development.
- Investigation and comparison of the criteria used by the Limbe Urban Council and HYSACAM (waste management unit) to locate waste sites, monitor groundwater around waste sites and control groundwater contamination.
- Groundwater analysis was conducted using available testing techniques in Mutegene, Cameroon and Cottbus, Germany. Water samples were collected from household wells, springs and one boreholes, because there were no monitoring wells for sample collection.

The quality of groundwater in this area was tested in order to ascertain the possibility and degree of contamination. The type and level of contaminants were also investigated.

Empirical data from Limbe Municipal Council and HYSACAM were used to highlight the constraints associated with solid waste management in Cameroon throughout the discussion. The main reasons for data collection were to investigate conceptual models and to consider different perspectives with regard to municipal solid waste management policy.

2.2 Site Visit

The first visit was made between December 2006 and February 2007. During this visit, the various municipal waste sites were visited and pictures taken. The water sample collection sites were also identified and secondary information was obtained. The methods of collection and disposal used by the LUC and HYSACAM were also identified and appointments for future interviews and discussions were made.

The second visit to Cameroon was made between December 2008 and March 2009 to get more primary and secondary information on climate, groundwater and waste management in Limbe. Field visits were organised to know the geology and hydrogeology of Limbe, the state of the Limbe municipal dumpsites, the waste management methods used, and the state and level of groundwater. Interviews were conducted both at the Limbe Urban Council and HYSACAM head offices. Pictures were taken to confirm observations. Finally, groundwater and soil samples were collected from municipal and home waste sites and analysed to know if there is groundwater contamination. Results obtained were faulty.

Hence, a third and final visit was made in April 2010 to complete the previous research in 2008/09. This trip was made because the results of the first sample analysis were only, partially obtained for water samples and nothing for the soil samples. This was also done to check if HYSACAM had started building a landfill as promised in 2009. Unfortunately, no soil samples were collected because of financial and time constraints.

2.3 Sample Collection

During the second visit, sample collection was done in some prominent areas in Limbe; prominent because these are areas which are densely populated and where “rich people” as well as “poor people” live. Soil and groundwater, as well as spring water samples were collected from 10 different areas. In each area, three groundwater samples of each specimen were collected. One of the samples from each area was marked as the microbial (mic) sample for microbial analyses. All samples were given the code Lim (number), for chemical tests or Lim (number) mic for microbiological sample tests.

Water samples were collected in prepared sample bottles and soil samples in plastic bags. Water samples were preserved in a cooler with ice blocks and cooling containers. The cooler was closed after collection at each site or point. Soil and water samples were collected from some points together and at others separately as seen in Table 6.

During the third visit, all seven samples were collected in one day (April 20, 2010) for microbiological and physico-chemical analysis in Mutengene, Cameroon and physico-chemical analysis in BTU Cottbus, Germany. Seven sample stations were used so as to reduce cost and were collected in seven well-sealed 50ml, 100ml and 1000ml bottles. For analysis in Cameroon, the 50ml bottles were used for microbial analysis and 1000ml bottles for physico-chemical analysis. The 100ml bottles were used to collect the samples for analysis in BTU Cottbus. Water was collected in a syringe and injected into bottles. The bottles were first rinsed with the sample water before collection, to minimise sample contamination and the probability of false results. At the end of each collection, the samples were labeled and put in a cooler.

Table 6: Water and soil samples collection stations

Sample no.	Groundwater and Spring Sample area	Soil sample stations
Lim 1	Cité Cape Limbo, Mokundange (spring)[x]	Cité Cape Limbo, Mokundange (spring)
Lim 2	Cold water (spring)	Karata dumpsite, Mokundange
Lim 3	Spring near cemetery at Motowoh	Cold water (spring)
Lim 4	Well 1, near cemetary, Motowoh	Cow market (former LUC dumpsite)
Lim 5	Well 2, near cemetary, Motowoh[x]	Well at Motowoh
Lim 6	Well at Motowoh[x]	Community Quarters
Lim 7	Community Quarters	Clerks Quarters 1
Lim 8	Clerks Quarters 1	
Lim 9	Clerks Quarters 2	

x Cancelled samples stations in April 2010 water analysis.

The samples were labeled Lx with L as Limbe and x as the station number (Table 7). They were collected in the following order; sample station L7, L1, L6, L2, L3, L4 and L5, that is, in-town moving outwards. This was done to minimize to and fro movements. There was no on-site titration and on-site electric conductivity (EC) calculations.

Table 7: List of sample collection stations

Code	Site name
L1	Cold water (Mile 2 Extension)
L2	Spring (New Town Cemetery)
L3	Well (Crab Quarters)
L4	Well (Community Quarters)
L5	Well beside FATECOL - Motowoh
L6	Well (Clerks Quarters)
L7	Borehole near Karata dump site

2.4 Data Analysis

The samples were analysed in three different laboratories. The first set of samples (2009) were analysed in the microbiological laboratory in the University of Dschang, Cameroon. These results were faulty for groundwater samples. No results were sent on soil samples. The second set of samples collected in 2010 were analysed in the laboratory of the Cameroon Baptist Convention (CBC) Central Pharmacy at the Quality Assurance Department, Mutengene, Cameroon and the hydrology laboratory of the Brandenburg

Technical University of Cottbus, Germany. These results are presented in tables and more specifically as microbiological and physico-chemical data as shown in Appendices II and III.

2.5 Presentation and Discussion of Results

Results obtained from laboratory analysis were presented in the form of tables, pie charts, figures using Microsoft excel. A biveriate Pearson correlation was carried in SPSS to find the relationship, as well as the significance of the correlation, between the parameters. The observations were backed by pictures, and information obtained from interviews and discussions. Then conclusions were drawn and recommendations made.

CHAPTER THREE: LITERATURE REVIEW

3.1 Solid Waste Management

The constant increase in waste generation, accumulation and management are worldwide concerns. However, factors like technology, industrialisation, life-style and economic standards determine the rate of waste generation for different communities. The increase in human activities and civilization makes waste generation increasingly unavoidable; hence there is the need for constant upgrading of waste management policies. These changes in waste management policy caused by the colossal generation of waste materials have led to an increase in the reuse and recycling of waste materials in developed countries (Delay et al, 2007).

Solid waste generated by municipal communities has two major components, namely, organic and inorganic. Waste generated in developing countries has higher organic content than that generated in developed countries. The organic components of waste can be comfortably divided into putrescible, fermentable and non-fermentable waste. Putrescible waste, which mostly comes from food preparations and consumption, decomposes very rapidly with visual unpleasantness and disturbing odours. Fermentable waste, with examples of crop and market debris, decomposes rapidly with no unpleasant accompaniments. However, non-fermentable waste resists decomposition and breakdown only very slowly (Diaz and Golueke, 1985).

Hence, environmental assessment requires test procedures to examine these waste materials before reuse. It should be noted that waste generation must be avoided as much as possible and when generated, recycling and reuse should be methods of priority in waste management; for example, demolition waste can be used for road construction. Notwithstanding the environmental risks presented by waste, reuse should be kept as minimal as can be. This implies that waste must be assessed according to their release of organic and inorganic pollutants. Required test procedures should be practicable and affordable to authority and laboratories (e.g. leaching tests), and should also reflect possible scenarios under natural deposition conditions (Delay et al, 2007).

The last decade has experienced the development and comparison of many leaching tests in Europe. For example, the German Federal Ministry of Education and Research (BMBF) developed and performed the batch and column leaching tests, with an aim to determine the source strength (the total mass flow caused by natural leaching) of porous waste materials with respect to inorganic pollutants. The high concentration of elements in seeping water in the early stage of elution can be reflected by laboratory column leaching tests, whose results could serve as basis for decision making. The eluent in batch tests are in constant contact with the examined material while the elution agent is constantly renewed in column tests. Therefore the question whether the measured or calculated average concentration should finally be employed in risk assessment (Delay et al, 2007). This technology or test is very expensive and so can be afforded only by few developed countries.

3.1.1 Definition of Waste and Integrated Waste Management

According to Batsone, (1989) cited in Awemo, (2000), waste is defined as something that no longer has any value or use. It is also defined in Webster Dictionary as leftovers, super flows, refuse no longer of use. Waste occurs in solid, liquid or gaseous forms. It is unfortunate to realise that too much waste is generated, but very little acceptable space exists for its permanent disposal (Botkin and Keller, 1995). Different types of waste should be disposed of in different ways as seen in Table 8.

Table 8: Typical treatment and disposal methods for different types of waste

Waste type	Incineration	Physico-chemical treatment	Biological treatment	Landfill	Recovery
MSW	X			X	X
Clinical waste	X				
Commercial waste	X			X	X
Effluents		X	X		
Acids and alkalis		X			
Heavy metals (sludges)		X			
Oils and Solvents	X		X		X
Resins and Paints	X				
Pesticides	X	X			
Chlorinated organics	X				
Biodegradable industrial wastes			X	X	
Reactive wastes		X			
Explosives	X	X			

Source: Petts and Eduljie, 1994

However, there is a recent concept called Integrated Waste Management (IWM), which involves a set of management tools like reuse, reduction, recycling, composting, landfilling and incineration. But the most important are the three Rs of IWM, which are reduce, reuse and recycle. The main objective of the three Rs is to reduce the amount of urban and other waste that must be disposed of in landfills, incinerators and other facilities. Fifty percent waste reduction can be attained if the following considerations are made:

- Better designs of packaging to reduce waste. This is an element of source reduction (10%)
- Establishing recycling programmes (30%)
- Large scale composting programmes (10%)

3.1.2 Types of Solid Waste

Solid waste according to the USRCRA (united States Resource Conservation and Recovery Act) includes liquid and gas. Its generation increases with increase in globalisation. Its generation cannot be controlled since it depends on the activities of people and the fact that it has many forms. These wastes may be generated as solid, liquid, sludge, gas or a combination of all (Oweis and Khera, 1990). The different types of solid waste include municipal, industrial and mineral waste.

Solid waste may be hazardous on non-hazardous depending on its form of generation and properties. Hazardous waste can cause potential risk to human health and the environment. Such waste must disposed of specially. Solid waste is referred to as hazardous if it is listed as hazardous waste (with organic or inorganic constituents), corrosive, toxic, ignitable and reactive.

Non-hazardous waste could be referred to as municipal waste. However, this study emphasizes on municipal solid waste, which represents the largest amount of waste generated in Limbe, and its management is of great concern to the community. The Limbe Community mostly produces more household waste, including small amounts of household hazardous waste. Household hazardous waste (HHW) contains toxic, corrosive, ignitable or reactive ingredients. These include pesticides, fungicides, oven and other cleaners, paints, automotive fuels and oil, polishes, paint removers, batteries, etc. These require special care when being disposed of in household waste. Improper disposal of HHW can include pouring them down the drain, on the ground, into storm sewers, or in some cases throwing them in the trash cans. The dangers of such disposal methods might not be immediately obvious, but improper disposal of these wastes can pollute the environment and pose a threat to human health. Many communities in Germany offer a variety of options for conveniently and safely managing HHW.

3.1.3 Municipal Solid Waste

Municipal Solid Waste (MSW) is waste generated in a municipality and this waste should be primarily managed by an urban council. Moreover, waste management is a global problem especially as most waste is only transported from one point to another without adequate management (Botkin and Keller, 1995). Waste produced in urban areas is dumped in landfills and might produce methane (CH_4) gas that can be burned as fuel. This gas is most often not collected for treatment or use and hence can pollute the air. Also, the disposal of waste on land is often poorly controlled and managed especially in developing countries (Westlake, 1995).

Rural areas worldwide suffer from illegal dumping of waste on roadsides. This form of waste disposal is liable to cause soil and water (particularly groundwater) contamination, and health hazards to plants, animals and people. Global world statistics indicate that 1.3 billion people lack access to adequate supply of safe water while 2 billion people do not have access to adequate sanitation (CNN News, 2006; UNEP et al, 1997).

3.1.4 Municipal Solid Waste Management (MSWM) Systems

MSWM systems in developing countries involves collection, transportation and disposal of waste while other options as recovery, recycling and reprocessing for energy still require consideration as in Fig 7 (Asong, 2010; Voigt, 2010). Developing countries face a problem of better waste management strategies because they do not have well documented data of waste type and generation. This knowledge could be the basis of sustainable waste management, that is, waste reuse, recycling, incineration, composting or landfilling (Shimura et al, 2001).

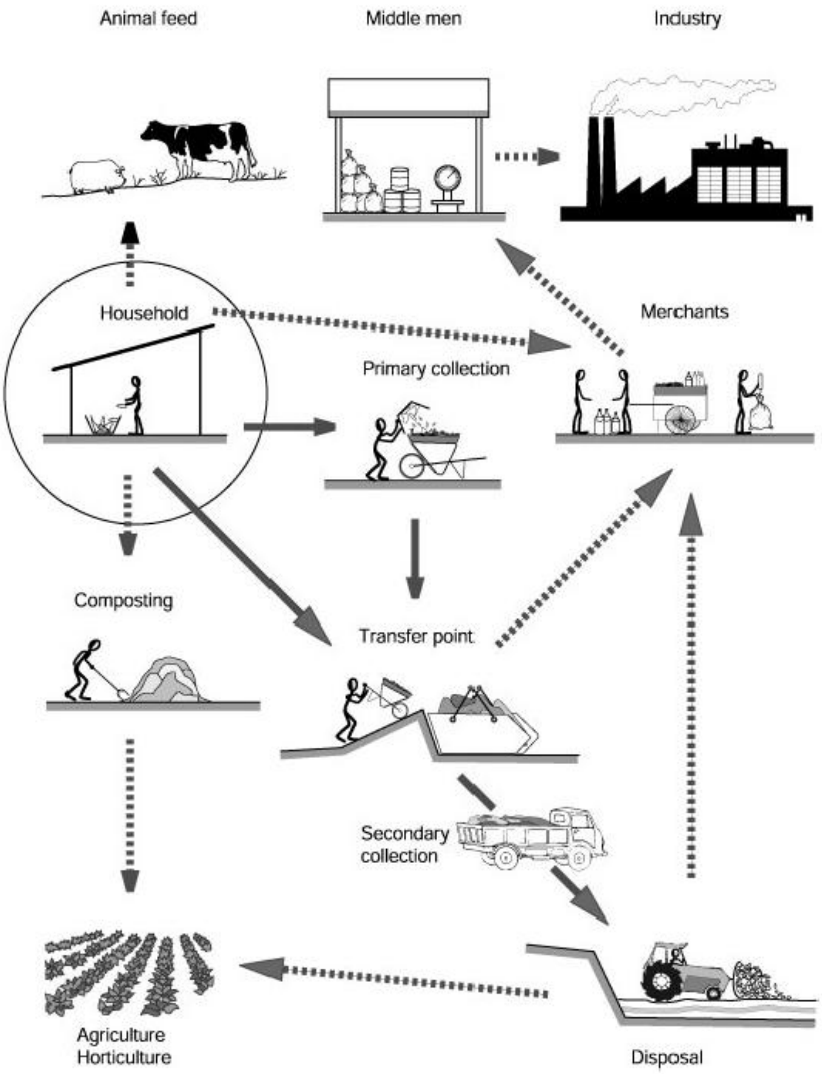


Figure 7: Typical elements of a solid waste management system in low- or middle-income countries

Source: Voigt, 2010

According to Achankeng, (2003) sustainability also requires the great need to manage MSW in a manner that is environmentally, socially, technologically and economically effective. This is very difficult for developing countries first of all because of illegal choices of waste disposal by households; secondly because of the lack of proper steps to waste disposal site selection; and thirdly because of improper implementation of policies and regulations that govern the operation of waste management facilities. This problem is further intensified by insufficient finances which are poorly managed, and the fact that MSWM is influenced by a complex and hard-to-understand interrelationship of environmental, socio-cultural, economic and political factors (Asong, 2010).

The objectives of municipal solid waste management are to guarantee hygienic disposal, protect the environment and resources (Busch, 2003). These should help ensure that waste is reliably collected and disposed of at fair and affordable prices with special consideration on the environment and man. The most effective way to implement sustainable MSWM is through the 5Rs which, in order of desirability, include Reduce, Reuse, Recycle, Recover and Residuals (Metro Vancouver, 2008).

Moreover, the collection and disposal of waste remains a problem because of repeated insufficient and inadequate waste collection and transportation facilities. This could be due to lack of finances, technical know-how, proper management skills and high rate of waste generation. Waste generated can be disposed of in the following ways:

1. On-site disposal, for example, mechanical grinding of kitchen waste and emptying of kitchen garbage into waste water pipe systems at the kitchen sink.

2. Composting, a biochemical process in which organic materials like kitchen scraps are decomposed to soil-like material.

3. Incineration, where combustible waste is burned at temperatures of 900°C and 1000°C (1650°F and 1830°F). These temperatures are high enough to consume all combustible material leaving only ash and non-combustible waste for disposal in landfill. This process releases some contaminants which are shown in Table 9.

Table 9: Contaminants produced from waste incineration

Dangerous substance	Path	Category	Remark
Organic compounds especially dioxins and furans.	Gas, fly ash, residue	Human toxicology	Very important, incineration is major contributor.
Volatile heavy metals, e.g., Cadmium, Lead.	Gas, fly ash, residues	Eco-toxicology	Important because of trans-boundary movement.
Hydrogen chloride	Gas	Acidification	Important
Metals, e.g. Arsenic, Cadmium.	Gas, fly ash, residues	Human toxicology	Important, carcinogenic.
Salt, e.g. chlorides.	Waste water, fly ash, residues	Ecotoxicology	Important, highly soluble, transported to surface water.

Source: Tapong, 2002

4. Open dumping is an old method where waste is piled up on the ground without covering or protection.

5. Sanitary landfills are designed to concentrate and contain refuse without creating a nuisance or hazard to public health and/or safety (Knödel et al, 2007).

3.2 Landfill

3.2.1 Definition and Types of Landfills

The most popular disposals method that has been used for the disposal of municipal and commercial waste is landfilling (Ahel et al, 1998). A landfill is a structure that is carefully designed and built into or on top of the ground so that trash is isolated from the surrounding environment (Wroblewski et al, 2011). This is the final waste disposal option and it is defined as the engineered deposit of waste onto and into land in such a way that pollution or harm to the environment is prevented and, through restoration, land provided which may be used for other purposes.

According to Bagchi, (2004) and Westlake, (1995), three forms of landfills exist according to the principles of dilute and attenuate; containment and entombment. The attenuate landfill is unconfined with minimal engineering thereby permitting leachate migration into the surrounding environment and groundwater. A containment landfill has a higher degree of site design, engineering and management exercising a level of control over hazards from landfill waste disposal. It involves the construction of a leachate collection pipe and a low permeable liner which restricts the percolation of leachate. This type of landfill is recommended for hazardous waste disposal. An entombment landfill is a containment landfill that prevents liquid infiltration, thereby storing waste in a relatively dry form. The different types of landfills include; sanitary landfills, MSW landfills, construction and demolition waste landfills and industrial waste landfills (Fig. 8).

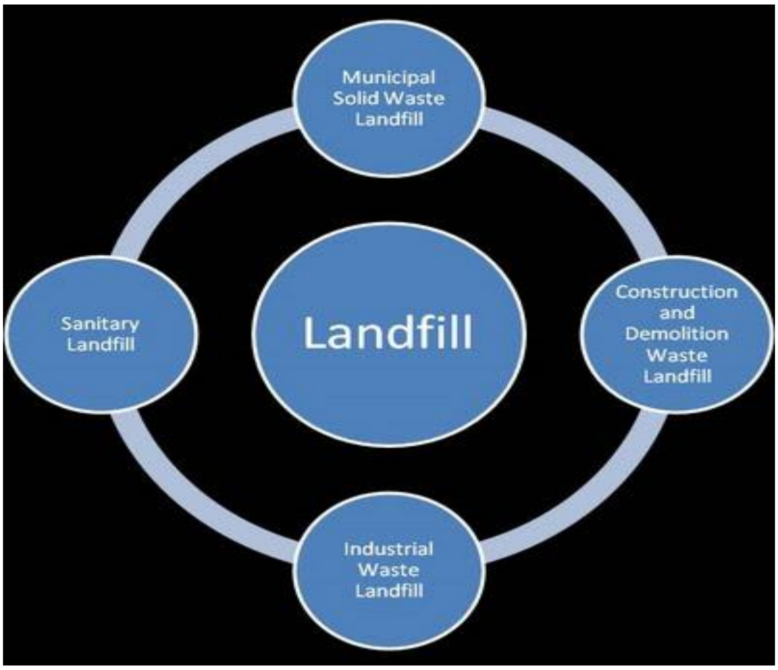


Figure 8: Types of Landfill

Source: Wroblewski et al, 2011

Landfilling is only sustainable if it is managed in order not to pass its effects onto future generations. At the end of its life-span, a landfill should not cause threat to man and the environment. According to Knödel et al, (2007) the knowledge and experience with waste disposal shows that numerous abandoned landfills must now be regarded as hazardous. As a matter of fact, impermeable layers at such sites are the most important barriers that prevent the spread or infiltration of contaminants and pollutants. Geological barriers are very important since the present-day techniques for constructing landfill sites prevent the spread of contaminants only for a given time. Other environmental considerations in landfill construction include:

1. Climate, such as type of precipitation, intensity and duration of rainfall, the distribution of rainfall within a basin and other climatic conditions that affect evaporation and transpiration.

2. Physical characteristics of the drainage basin (physiographic factors), like land use, soil type, area, shape, elevation, slope, orientation, type of drainage net, the extent of indirect drainage and artificial drainage (Wisler and Brater, 1959).

3.2.2 Municipal Solid Waste or Sanitary Landfill

This could also be referred to as a municipal or sanitary landfill. Heterogeneous (residential and commercial) mixtures of waste are disposed of in such landfills. The types of waste mostly include food and garden waste, paper, plastics, rubber, textiles, wood and ashes. At the end of each day the waste must be covered with soil and compacted. New landfills should have liners, leachate and gas collection systems and final covers, so as to minimize the chances of groundwater contamination. The dimension of the cell will depend on the volume of waste received and the available cover material (Oweis and Khera, 1990). Municipal landfills are well noted for the release of 4 groups of contaminants. These include:

- Complex organic matter like chemical oxygen demand (COD) or total organic carbon (TOC)
- Inorganic macro-constituents like Ca, Mg, Na, K, NH_4, Fe, Mn, Cl, SO_4, HCO_3
- Specific organic contaminants
- Toxic metal which include heavy metals like Cd, Zn, Pb, Cu, Ni, Cr (Ahel et al, 1998).

The following are necessary components of a landfill; subgrade, liners (clay, flexible membrane and admixed), leachate collection and detection systems, pipes for leachate collection, gas vent, monitoring wells, capping and geotechnical instrumentation to monitor settlements and assess stability (Oweis and Khera, 1990). Landfills are said to have the greatest adverse impacts on the environment (see Fig. 9).

Sanitary landfills unlike open dumps are advantageous because they protect public health and the environment. In constructing a landfill, there is the possibility to minimise groundwater contamination from leachate through the building of leachate collection pipes. This will consequently minimise the release of heavy metals from leachate. In building a gas collection pipe, the risk of release and contamination of greenhouse gases is curbed. Sanitary landfills involve the daily covering of waste and this helps reduce waste invasion by pests like flies and mosquitoes; birds and rats, and prevents the release of bad odour from decomposing waste (O'Leary and Walsh, 1993; Tapong, 2002).

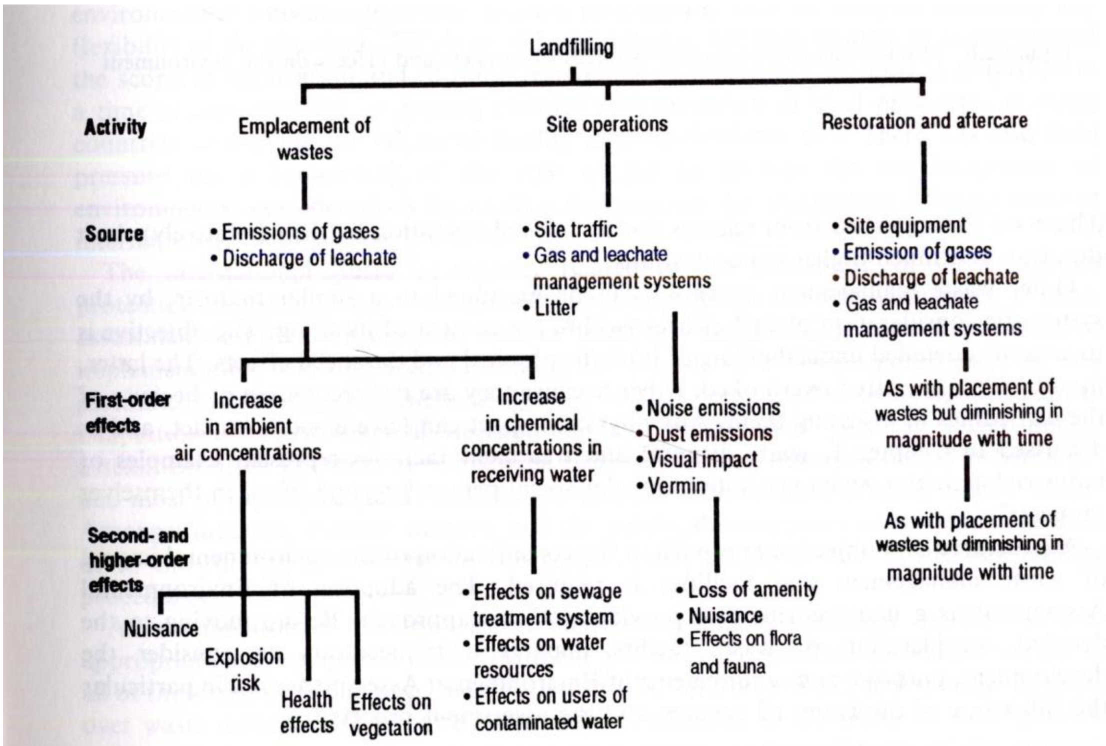


Figure 9: Landfilling-sources of impacts and effects on the environment

Source: Petts and Eduljie, 1994

3.2.3 Landfill Site Selection and Investigation

3.2.3.1 Site Selection

The steps to landfill site selection are not based on personal judgment, but on scientific principles. These steps involve all stakeholders including the public (Voigt et al, 2006). Landfill site selection depends on a variety of criteria, some of which include, proximity and road accessibility to site, the geological and hydrogeological stability of the site, and environmental, economic and political issues (Oweis and Khera, 1990; Williams, 2005). Politics in this case implies public participation in site selection. The most important issue is selecting a site where environmental protection is natural in the event of technological failure like liner failure. Site selection involves a number of criteria which ought to be fulfilled (see Tables 10 and 11) as well as EIA. These criteria narrow the number of sites, and lead to detailed site investigation and analysis. Public participation and geological investigations are most important in the process of site selection.

Table 10: Criteria for site selection

Economic	Socioeconomic	Environmental
Development land	Archaeological and historical sites	Wetlands
Slope	Dedicated land	Threatened and endangered species
Utilities	Land use	Slope
Site access	Noise impact	Air quality
Flexibility	Sensitive receptor	Odours
Capacity	Social impact	Aesthetic impact
Development, operation and maintenance cost		Flood plains
Compatibility with existing solid waste management systems		Soils
		Geology
		Groundwater
		Monitoring
		Surface and groundwater hydrology
		topography

Source: Oweis and Khera (1990)

Table 11: Definitions and significance of siting criteria

Criteria	*Sub-criteria*	*Definition*	*significance*
Soils	Permeability	Soil property that governs the rate at which water moves through it	Subsoil permeability impacts release of pollutants to groundwater; lower subsoil permeability is preferable for siting
	pH	Indication of acidity and alkalinity (pH 7=neutral)	Characterises tendency of soil to absorb heavy metals; greater pH is preferable for siting
	Cation exchange capacity (CEC)	Capacity of soil to exchange cations expressed as a sum for all exchangeable cations	Indicates the ability of soil to attenuate some contaminants, particularly heavy metals; higher CEC is preferable for siting
	Surficial soils	Unconsolidated material at the Earth's surface	Affects degree of attenuation and the need for liners; Surficial soils with lower permeability are preferable for siting
Geology	Bedrock and outcropping		Carbonate rocks are susceptible to solution; fractured rock facilitates pollution migration; sites with more overburden are preferable
	Continuity and mass permeability	Related to open discontinuities, solution channels	Controls the potential for migration of contaminants
	Faults	Mapped plans and zones of rock along which displacement has occurred	Impacts the stability of facility and potential release of pollutants
Groundwater	Aquifer/well yield	Relates to geological formation or group of formations capable of	Sites with high aquifer capabilities may be off-limits for some facilities

		yielding usable quantities of groundwater to wells or springs	
	Aquifer use	Use of aquifer could be within a specific distance from facility, potential, or sole source (solely or principally supply drinking water to a large percentage of populated area)	Impacts the water supply; aquifers with low actual or potential use are preferable for siting purposes; sole-source aquifers are considered very significant even if yields are low
	Groundwater quality	Natural groundwater quality as measured against drinking water standards	Areas with poor natural groundwater quality represent more suitable locations, all else being equal
	Groundwater flow system	Refers to the occurrence and movement of groundwater with regard to direction and velocity	Sites where direction of groundwater flow is a way for use, or where flow is upward, or where water is deep, as else being equal
	Seasonal high groundwater level	The maximum level to which groundwater is expected to rise	Unsaturated zones act as a barrier (no direct mixing) between base of facility and groundwater. Most regulations specify a minimum of 1.5m (5ft)
Monitoring aspects	Monitoring aspects	Refers to RCRA requirements for groundwater monitoring	Sites that are easier to monitor (e.g. presence of a layer of sand and gravel) or a known discharge body like a lake
Cover	Cover material	Refers to earth material (available on site) used for daily waste sealing	Sites with abundance of workable and relatively impervious soils are preferable, all else being equal
Slope	Slope	Deviation of the land surface from the horizontal measured as the average topographic relief for the site	Impacts release of contaminants, site development and operation. Slopes greater than 15% or 22% are considered too steep
Surface and groundwater hydrology	Proximity to streams/lake	Refers to overland proximity and protected uses of the nearest lake or stream	Impacts opportunity for runoff and contaminants polluting lakes/streams
	Proximity to wells/aquifer	See aquifer under geology above	Impacts groundwater resources: sites closer than 800m (2500ft) to a high yield well (70g/m) may be excluded
	Proximity to flood-prone areas	Land areas inundated by flood of specified frequency (usually 100years)	Impacts transport of hazardous waste
	Proximity to recharge areas	Refers to lands draining to existing or planned storage reservoirs	Impacts drinking water supply
Topography	Slope erodibility	Migration of soil particles by surface water or other natural phenomena	The potential of soil erosion impacts facility construction and operation
	Run-on and run-off	Run-off refers to rainwater or leachate that drains overland away from the facility; run-on refers to drainage overland on to any part of the facility	Sites with little need for control of run-on from upland and slow run-off are preferable. Run-on is usually controlled by berms (level spaces, shelves, or raised barriers separating two areas), stream diversion, etc. Run-off control is impacted by velocity of water traversing the site

Source: Oweis and Khera (1990)

In selecting a new disposal site, all regulations that govern landfill construction should be considered. The proposed site should be free of immediate and clear hazards like floods, earthquakes, landslide, tsunamis and aquifer contamination. A map showing these exclusions must be produced and should include topography, precipitation, temperature, man-made water bodies, floodplains, earthquake- and landslide-prone areas, soil, ecological aspects, etc. The following steps are important in the process of site investigation:

1. Public participation is important because the population suffers the effects of poor site selection and should have a right to all steps of site investigation. This will enhance the process.

2. Geological investigation involves the use of geological information to produce recommended areas for site investigation map (RASIM) which will be understood by everyone. The proposed site must undergo detailed investigation for geology and hydrogeology. Depths of between 50-150m and surface area of between 0.1-1km^2 around proposed site must also be investigated. Investigation should reveal if geological barrier can minimise contamination.

3. Hydrogeological investigation will include the thorough investigation of all major aquifers in order to know the groundwater condition. Climatic (humidity, precipitation, temperature, runoff, evapo-transpiration) and hydrogeological (water content, water table, direction and rate of flow, hydraulic conductivity, value of aquifer) condition must be investigated and well tests made so as to minimise contamination and enhance monitoring.

4. Geophysical investigation

5. Geochemical and hydro chemical investigation involves soil and water analysis for chemical component like anions (Cl, SO_4, NO_3, HCO_3, CO_3, etc.), cations (Na, Ca, Mg, K, Al, Mn, Fe, SI and NH_4), organic (phenols, mineral oils), heavy metals. (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn), inorganic and others (BOD, COD, DO, EC, pH, TOC, DOC, etc.). Sample collection and analysis should be done according to international standards and should minimise errors especially at sample collection phase.

6. Natural attenuation capacity must also be considered with two of the most important processes being retardation and biodegradation of contaminants. The preferred barrier should have a clay-rich substrate with low hydraulic conductivity. Biodegradation is most important because it reduces the volume of contaminants and retardation occurs through sorption on fine-grained material and organic components. Lab tests must be conducted to determine the possibility of retardation and biodegradation through batch and column tests. Batch tests are used to estimate the parameter of sorption and transformation like biodegradation, while column tests would estimate the parameter of transportation, retardation and exchange between different phases like soil, air and water.

7. Geotechnical stability will include aerial photographs which will determine instability like subsidence from landslide earthquake, sinkhole, floods, etc. Both landfill base and body stability are important as they ensure the functionality of seepage collection, base and body seals (Voigt et al, 2006).

3.2.3.2 Site Investigation

The main aim of site investigation is to minimise the impacts of waste disposal on the environment. A thorough understanding of site geology is most required in site investigation and assessment phase (Knödel et al, 2007). It is important to evaluate surface and sub-surface conditions of the proposed site for proper design, operation and maintenance (Oweis and Khera, 1990). Data must be collected through remote sensing, soil and rock samples, geophysical methods, *in situ* tests which measure the properties of soil, rock and waste materials, groundwater quality and profile. Also, environmental safety measures are also very important and must be taken into consideration.

The investigation of the surrounding area must include that part of the geological barrier that is needed for contaminant retention and that part of the regional groundwater system that will possibly become contaminated. Each landfill (abandoned or operational) is located within a groundwater system of several tens of square km. A detailed study must be carried out in an area of 0.1-1km^2 around the site itself. Depths of up to about 50m below must be investigated in abandoned and planned waste disposal sites. This investigation, if extended up to about 150m, is required to obtain information on the groundwater system. Mapping scales of 1:10000 or larger are needed for detailed geo-environmental assessment of landfills. Aerial photographs made at different times can reveal changes at the site suspected to be hazardous.

The objectives of site investigation must be well defined. Also important is the fact that suitable methods should be used to achieve objectives. Before establishing a project it is important to determine its objectives and goals, so that most suitable techniques and methods are used. Site investigation is active environmental protection and should be carried out in at least two phases (Knödel et al, 2007; Voigt et al, 2006):

Orientating Investigation: This method that is accompanied by reconnaissance site survey and historical investigations (through interviews) are view of previous use of the site. It also requires the following information from maps and other achieved data;

- Topography, land use and vegetation, settlements, roads and railways
- Climate, precipitation, temperature, evapo-transpiration, direction and velocity of wind, and the frequency of strong winds
- Hydrological and hydrogeological conditions: streams, lakes and ponds, springs, wells, use and quality of surface and groundwater, runoff, water balance, aquifer/aquiclude properties and stratigraphy, groundwater table, and groundwater recharge and discharge
- Geology: soil, geological structure, stratigraphy and lithology
- Ecological aspects like nature reserves, protected geotopes, water protection areas

Detailed Investigation and Assessment: The following must be considered;

- Geology: thickness and lateral extent of strata and geological units, lithology, homogeneity and heterogeneity, bedding conditions and tectonic structures, features, impact of weathering
- Groundwater: water table, water content, direction and rate of groundwater flow, hydraulic conductivity, value of aquifer
- Geochemical site characterisation: chemical composition of soil, rock and groundwater, estimation of contaminant retention
- Geotechnical stability: the geological barrier must be capable of adsorbing strain from the weight of a landfill, slag heap or industrial building
- Geogenic events: active faults, karsts, earthquakes, subsidence, landslides
- Anthropogenic activities: mining damage, buildings, quarries, gravel and clay pits, etc.
- Changes in soil and groundwater quality (Knödel et al, 2007; Voigt et al, 2006).

Geological and hydrogeological studies should be used to investigate lithological structures, to determine the homogeneity of the rock, to locate features, to determine the permeability of the rock with respect to water, gas and various contaminants, to assess the mechanical stability of the ground and to obtain data on the groundwater system. The main task of geological and hydrogeological surveys would be to gain information directly by examining outcrop, digging trenches and drilling boreholes, conducting hydraulic tests (e.g. pumping and tracer tests) in wells to determine hydraulic properties *in situ.* Drilling would entail taking rock, soil and groundwater samples to determine physical, chemical, petrographic and mineralogical parameters. Special laboratory experiments should be carried out to estimate migration parameters and the texture of rock and soil samples. On the other hand, geophysical and geochemical methods should be used to delineate and monitor operating and abandoned landfills as well as to determine the spread of contaminants.

Landfill barrier systems should also be taken into consideration and serious measure taken. It is advisable to take the Multiple Barrier Concept (MBC) approach which is made up of the planning, construction, operation and follow-up care of a waste site. Groundwater monitoring during the operation phase and after-care are also part of MBC. It was introduced in Germany in 1993 under the regulation "Technical Instructions of Waste for Human Settlement (TASi). It consist of two main barrier systems; technical and geological barriers which could further be divided into three barriers; the landfill body, landfill sealing, and drainage system and the landfill site (geological barrier) as shown in Fig. 10. Landfill and barrier construction must be done such that drainage water is collected through outflow from waste site and this will imply that the landfill should be constructed as a heap and not fill existing pits. This will also determine the type of waste to be disposed of at the landfill. Such waste must have minimised elution behaviour and should produce leachate with long-term chemical stability and the most minimal possibility of toxicity. It should constitute low concentration of organic components. If this is achieved the waste then in turn acts as a barrier (Voigt et al, 2006).

Technical barriers include combination systems of mineral seals, plastic membranes, drainage systems which offer long-term functionality (drainage beds) and gas collection systems (gas drainage). A technical barrier retains leachate for the first few years until it is chemically stable. The seal should provide access to leachate for monitoring. Surface seals should be decided at the end of the deposition process and should not provide room for cracks. Bitumen seals and capillary barriers with improved characteristics are safer since clay seals crack when dry.

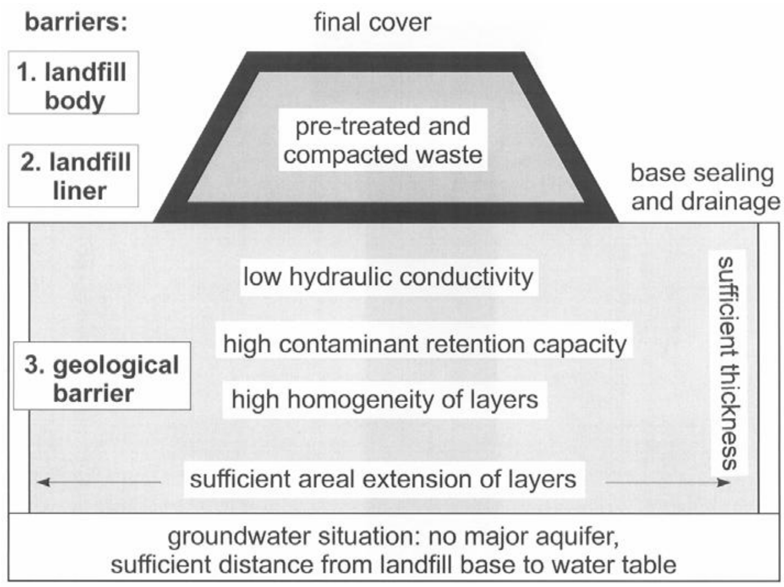


Figure 10: Scheme of the Multiple Barrier Concept (MBC)

Voigt et al, 2006

Geological barriers are special and important to MBC because they comprise consolidated and unconsolidated rocks which are naturally arranged, slightly permeable and several meters thick. They should have a high pollution retention capacity that is beyond the dumping area. In areas where geological barriers are doubtful, technical barriers must be constructed such that the errors are corrected. These, unlike geological barriers, are very expensive.

3.2.4 Groundwater Monitoring

Numerous research reports have revealed that landfill and waste disposal sites are a common source of groundwater contamination, especially in cases where there are provisions for leachate collection (Ahel et al, 1998). Monitoring of groundwater helps to minimise contamination of the resource and particularly that used for drinking. As a result, groundwater monitoring is very important in the management of all types of landfill. Each landfill requires monitoring wells which are used to monitor the state of groundwater in the uppermost aquifer. This will help to determine the state of groundwater before, during and after landfill construction and management. Monitoring should continue at least thirty years after closure of the site.

RCRA requires at least one hydraulically up-gradient well to determine impacts of the landfill on groundwater in the uppermost aquifer and at least three hydraulically down-gradient wells to detect the significant amounts of hazardous waste constituents migrating from waste to area to uppermost aquifer (Oweis and Khera, 1990). Parameters like phenol, Cl, Fe, Mn, Na and SO, and indicators like pH, electric conductivity, TOC are very important in determining the quality of groundwater and the degree of groundwater contamination, respectively. Annual and semi-annual tests are required to assess these parameter and indicators, respectively.

One very important way of avoiding further groundwater contamination around a waste site is to cover the dump site and the adjacent areas with a one-metre (3.3ft) thick layer of compacted clay and a polyethylene plastic cover to reduce surface water infiltration. This method greatly reduces the amount of water that seeps through the soil. Water (leachate) that successfully seeps through should be collected and treated through leachate collection pipes.

3.2.5 Stages of landfill development and design

In the process of landfill construction, certain things must be done to ensure that the fill is secure. EIA is one of the first steps in a landfill project. A landfill should be constructed such that its capacity allows for use for a period of 15-30 years. The capacity of the landfill site is an important determinant of the amount of waste, the amount of intermediate and daily cover required and the thickness of the capping system (Williams, 2005). Landfill waste density will depend on the degree of pre-compaction before disposal, variation in waste component, the amount of intermediate and daily cover and the rate of biodegradation. It is necessary to provide a drainage system for the collection of rainwater or runoff to reduce excessive water infiltrating waste.

There is also the need for leachate and gas collection systems, which will prevent the contamination of groundwater and atmosphere, respectively. A leachate collection system is made up of a drainage layer, leachate trench and pipe, leachate line clean-out ports, a leachate collection pump and lift station, and a leachate storage tank. Generally, the leachate pipes are put in trenches filled with gravel. In addition to this, the gas collection system is needed to collect and use the gases produced in the landfill. A passive or active venting system could be used depending on the type of design, soil surrounding the landfill, distance of landfill from residential area, possibility for future use of landfill after closure, country or state regulations and type of waste. Attenuate landfills have a high degree of landfill gas migration than containment landfills (Bagchi, 2004). Passive venting systems are used in a landfill where gas production is low and migration is not expected, while the active venting system is used in cases where gas production and migration is unavoidable. The former is good for small municipal landfills of about 40,000m^3 and non-putrescible containment landfills. The latter is made up of a series of deep extraction wells which are connected by a header pipe to a blower. This pipe series sends the gas for reuse for energy purposes, to an on-site burner or to the atmosphere.

Current landfills unlike those of the past are referred to as designed and managed engineering project used as advanced treatment and disposal option (Williams, 2005). As a result, the barrier systems used will depend on the type of waste to be disposed of in the landfill. The types of barrier systems and the waste emplaced in the landfill are shown in Figure 11. The barrier system should include natural or geological barrier and an artificial or synthetic sealing system which contains leachate and gas in the landfill. Geological barrier will depend on the geological and hydrogeological conditions underneath the landfill and surroundings. A leachate sealing and collection system should be provided to ensure the minimisation of leachate escape from fill.

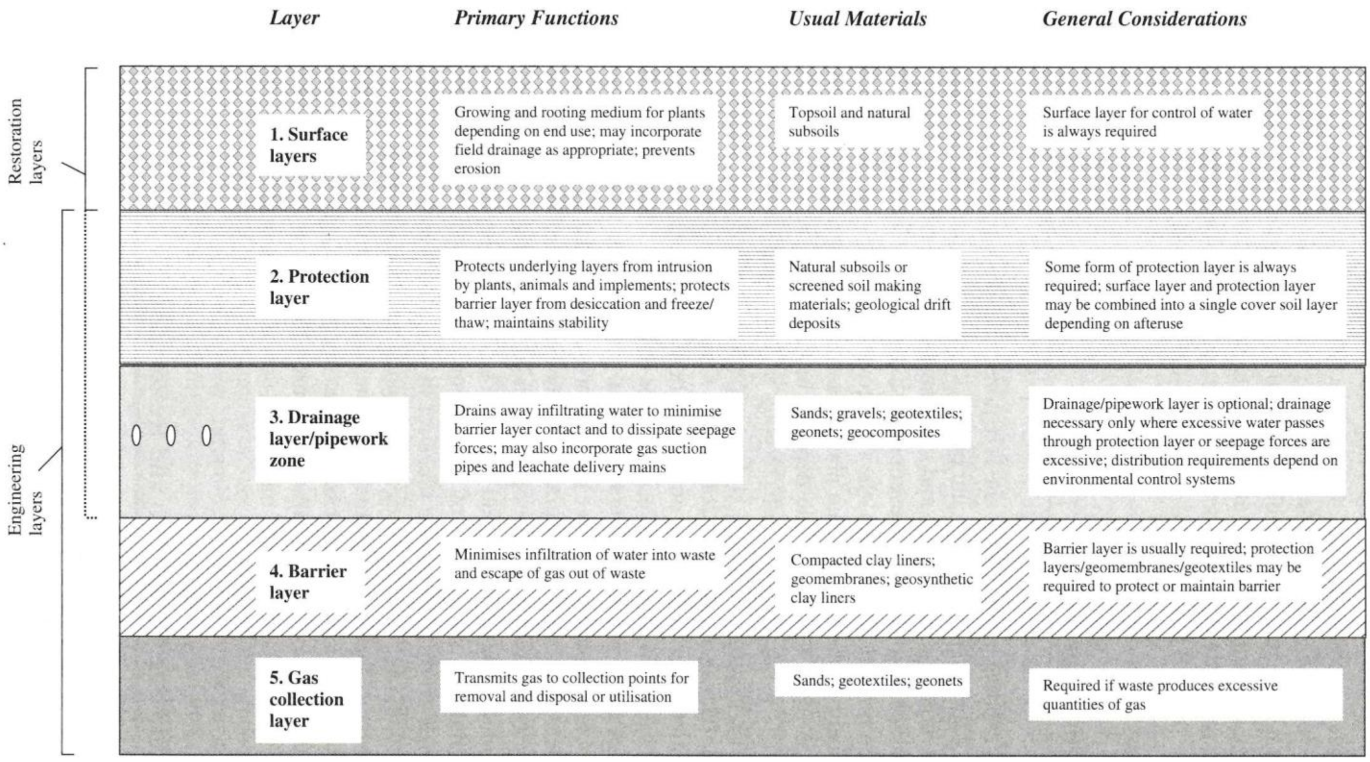


Figure 11: Components of a waste landfill capping barrier

Source: Petts and Eduljie, 1994

A landfill cover, which is multi-layered with each layer having specific functions, is needed so as to minimise water infiltration. These layers include, top soil, protective layer, drainage layer, barrier layer and grading layer (Bagchi, 2004).

3.3 Groundwater and Aquifer

Groundwater is an important source of water supply throughout the world and its use in irrigation, industries, municipalities and rural homes continues to increase. It is commonly understood to mean water occupying all the voids within a geologic stratum. Monkhouse and

Small, (1978) define groundwater as the body of water derived from percolation that is contained in the soil, subsoil and underlying rocks above the impermeable layer. This implies that groundwater is found beneath the surface of the earth within the zone of saturation. Wisler and Brater, (1959) refer to groundwater as water below the water table and above soil moisture. The region above the water table is divided into three different zones, namely,

1. The capillary zone found above the water table at a distance ranging from about 0.3-2.4m or 3m (1-8ft or 10ft) and is referred to as the capillary fringe.

2. Intermediate zone that is found between the capillary and soil zones.

3. Soil zone, which is the depth of overburden that is penetrated by the roots.

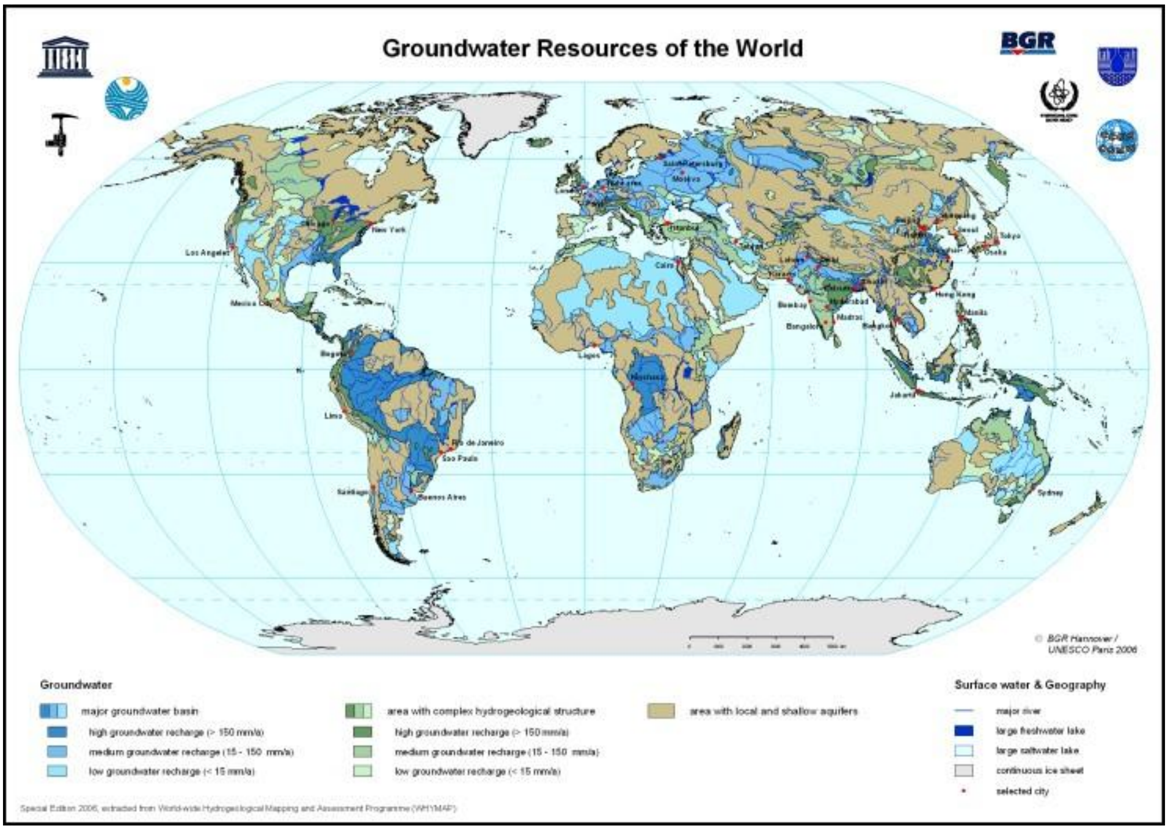


Figure 12: Groundwater resources of the world WHYMAP (simplified after the 1: 50 000 000 scale version of the map; source: BGR, Hannover)

Source: BGR, Hannover and www.fao.org/gtos/doc/ECVs/T03/T03-Groundwater-report-v05.doc, 2008

The occurrence of groundwater is highly dependent on the geology of an area (Fig. 12). Groundwater moves as a result of factors like void spaces (porosity) and resistance (permeability: a measure of the rate at which water moves in the soil) (Logan, 1995). The earth has interstices which vary in shape and size, even though most of them are small. These small interstices transmit water, while isolated (unconnected) ones cannot transmit water. The degree to which a rock contains interstices is referred to as porosity (Wisler and Brater, 1959).

Porosity is defined by Ward and Elliot, (1995) as the measure of the amount of open spaces in clay soils and rock layers which may contain water. It could also be defined as a measure of void spaces (Logan, 1995). The porosity of rock or unconsolidated material ranges from less than 1% to more than 50%. Porosity of less than 5% is referred to as small; that between 5%-20% is medium while that more than 20% is large (Wisler and Brater, 1959). Porosity, soil water content, texture, density, organic matter content and hydraulic conductivity (how fast water flows through certain soils and rock layers) are some of the soil properties that influence the rate of water infiltration (Ward and Elliot, 1995).

Folklore holds that the presence of soil protects groundwater quality by "filtering" contaminants out of recharge water. Present knowledge, however, indicates that the capacity of soils and the intermediate vadose zone (the area below the crop root zone that lies above the permanent water table) to hold back potential contaminants as they move towards groundwater, is limited. The major processes that determine the fate of contaminants in soil and their potential to leach into groundwater are now well understood. This knowledge can be used to reduce or eliminate contamination of drinking water supplies. However, some important factors that contribute to quality considerations of groundwater include:

- The mineral composition of aquifer rocks,
- The general geo-hydrologic framework of the area,
- The potential of groundwater mixing and the occurrence of interactive geochemical processes,
- Activities of man relative to the recycling capability of the aquifer (Logan, 1995).

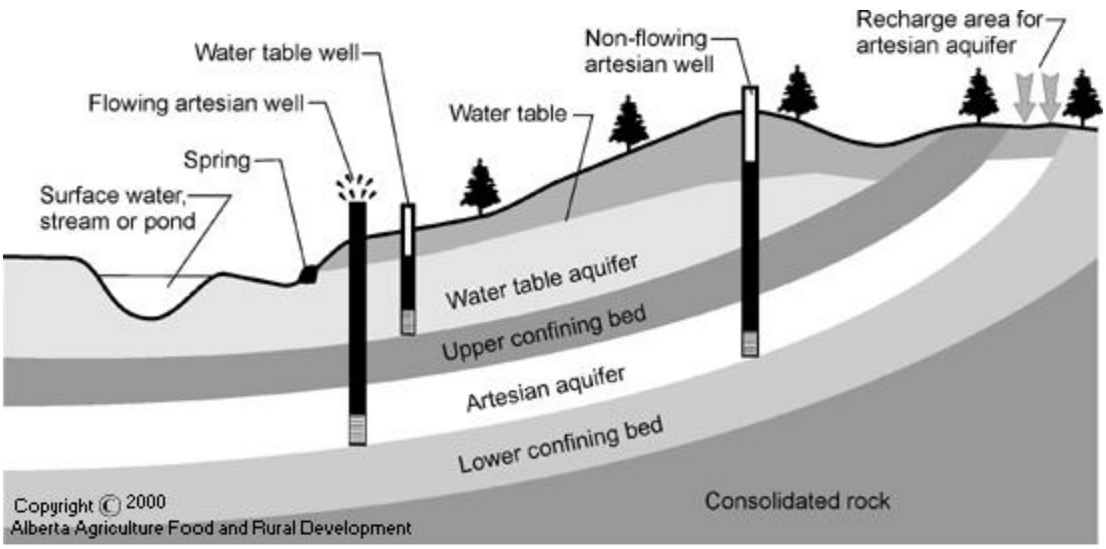


Figure 13: Types of aquifers

Source: Government of Alberta, 2008

An aquifer is a water-bearing soil or rock that can release its water in sufficient quantities to make it economically feasible to develop for water supply (Logan, 1995). It is the geologic layer that is filled with water and could transmit enough water to supply a well under normal hydraulic gradients. There are two main types of aquifers, namely, confined and unconfined (Fig. 13). Confined aquifers receive water from distant sources and are protected by an impermeable layer. Water in such an aquifer is subjected to pressure that is greater than atmospheric pressure. The surface to which water from these aquifers would rise is called the piezometric surface. Wells drilled in confined aquifers are called artesian wells and the aquifers are referred to as artesian aquifers (Logan, 1995). Artesian aquifers when drilled use artesian pressure to force water into the well. Unconfined aquifers are found in areas with permeable material, thereby allowing easy movement of water into groundwater. The quantity of water in such aquifers is dependent on seasonal changes. Unconfined aquifers are more liable to contamination because they lack the impermeable layer that protects the seeping of contaminants from other areas. Water in such aquifers occurs at atmospheric pressure.

3.4 Groundwater Contamination from Landfills/Waste Disposal Sites

Place of Origin	Potential Groundwater Contamination Sources			
	Municipal	**Industrial**	**Agricultural**	**Individual**
At or Near the Land Surface	• air pollution • municipal waste landspreading • salt for de-icing streets • streets & parking lots 	• air pollution • chemicals: storage & spills • fuels: storage & spills • mine tailing piles 	• air pollution • chemical spills • fertilizers • livestock waste storage facilities & landspreading • pesticides 	• air pollution • fertilizers • homes ○ cleaners ○ detergents ○ motor oil ○ paints • pesticides 
Below the Land Surface	• landfills • leaky sewer lines 	• pipelines • underground storage tanks 	• underground storage tanks • wells: poorly constructed or abandoned 	• septic systems • wells: poorly constructed or abandoned 

Figure 14: Potential sources of groundwater contamination

Source: Voigt, 2010

Landfill contamination is the degradation of the natural quality of groundwater due to human activities as shown in Figs. 14 &15 (Boulding, 1995). Todd and Mays, (2005) go further to define groundwater contamination as artificially induced degradation of natural water quality. It is not a new problem, but the occurrence of groundwater contamination has increased over the years because of increased globalization and generation of waste. Soil and groundwater contamination depends on the effect of soil moisture in two ways:

- If the soil is quite dry at the start of a rain, the wetting of the top layer creates a strong capillary potential just under the surface which supplements gravitational force in causing infiltration.

- When subjected to wetting, any colloids present in the soil swell and reduce the infiltration capacity (the maximum rate at which a soil in any given condition is capable of absorbing water) during the initial period of rainfall. Soil moisture is usually high in the rainy season and low in the dry season (Wisler and Brater, 1959).

The contamination of groundwater could be intentional or unintentional (neglect or accident). It could occur through recharge from surface water, direct migration, infiltration or inter-aquifer transfer (Boulding, 1995). Recharge from surface water could occur if the groundwater table lies below a stream, river or other water body or through flooding. Direct migration of contaminants to groundwater is possible if there is a breakage of storage tanks or transportation pipe located in the saturated zone.

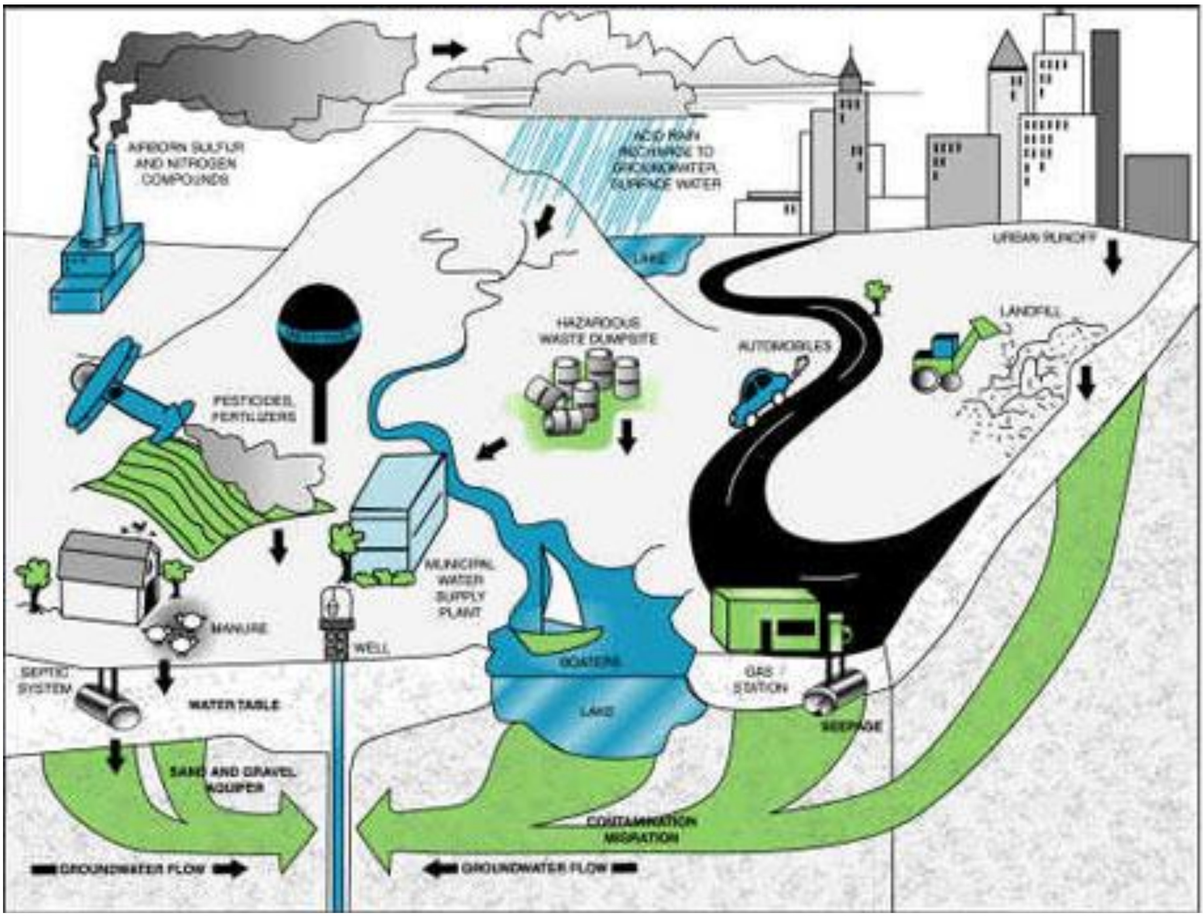


Figure 15: The water cycle and potential sources of groundwater contamination

Source: Voigt, 2010

Infiltration is the process whereby water enters the surface strata of the soil and moves downwards towards the water table (Logan, 1995). This is probably the most common mechanism of groundwater contamination (Boulding, 1995). Infiltrating water passes through an unsaturated to a saturated zone under the influence of gravity thereby replenishing soil moisture and the excess moves downwards to form groundwater (Logan, 1995; Wisler and Brater, 1959). Water infiltrating a contaminated zone may dissolve contaminants forming leachate with organic and inorganic constituents. The leachate then percolates down to the saturated zone where the contaminants spread vertically due to gravity and horizontally in the direction of groundwater flow (Boulding, 1995).

Inter-aquifer transfer (exchange) can occur through hydraulic communication between contaminated and uncontaminated aquifers. This normally occurs where a well is dug deep enough to access more than one water-bearing unit as shown in Figure 16 (Boulding, 1995). Wells which are not pumped and contain water from two different water-bearing units will have water from the unit with greater potential moving to water with lesser potential. If the water from the former is contaminated then the latter will also be contaminated. Abandoned wells from landfills could also be a source of inter-aquifer exchange.

Figure 16 also shows a well that has been abandoned and improperly managed with a corroded casing. This well used to tap a lower uncontaminated aquifer. Because the water is no longer tapped, it has been contaminated by water from a contaminated overlying zone through the corroded casing. Abandoned wells and landfills with depths close to groundwater tables could also cause direct migration of contaminants to groundwater. A second well nearby can be easily contaminated in the course of pumping even though the rate of contaminant movement is slow through a confining layer than the direct connection of an abandoned well.

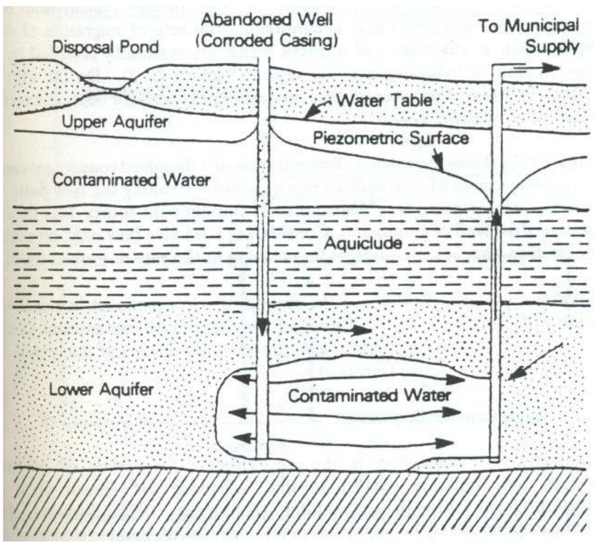


Figure 16: Vertical movement of contaminants along an old, abandoned or improperly constructed well

Source: Boulding, 1995

Soil surface conditions that affect infiltration include: compacted soil, vegetation, topography, slope and roughness of the surface, and human activities (Ward and Elliot, 1995). Other factors that affect infiltration capacity include:

- Compaction due to rain, for example, the surface of exposed clay will become virtually impermeable and hence minimise infiltration.
- Vegetation cover also compacts soil and reduces infiltration capacity.
- In-wash of fine material, such as very dry soil has very fine particles at the surface. In case of rain, these fine particles then occupy interstitial spaces, hence reducing infiltration capacity.
- Compaction due to man, for example, pedestrian and vehicular traffic and other activities like grazing, playgrounds and roads lead to the impervious nature of the soil (Wisler and Brater, 1959).

3.4.1 Important Terms Related to Contamination

A contaminant, unlike a pollutant (any substance whose presence has a potential to cause harm through environmental degradation, or to human and animal health), is a substance whose presence is normally expected. In the case of water, this is any substance other than a chemical substance (Logan, 1995). Boulding, (1995) defines a contaminant as any physical, chemical, biological or radiological matter or substance in water. He goes further to say that contaminants could also be referred to as all solutes which are introduced into the hydrologic environment because of anthropogenic activities. The above definitions do not specify the difference between various sources and levels of contamination.

There are two types of contaminants, namely, point source and non-point source contaminants. Point source contaminants are those that are discharged to surface or groundwater from a defined source, e.g. industrial discharges, municipal effluents, etc. Non-point source (also called diffused source) contaminants are watershed sources of contaminants that are distributed by runoff or percolation from land as a result of different land use activities like agricultural fertilisers and pesticides (Logan, 1995).

The principal process of movement of contaminants in soils and groundwater is mass flow. Dissolved constituents in water move through the soil; implying that water is a carrier of contaminants. Mass flow is affected by properties of the contaminants, the soil, the intermediate vadose zone and the aquifer, climatological factors, and vegetation patterns.

Groundwater hydrology is a part of hydrology that concentrates on the storage and movement of water beneath the ground surface (Wanielista et al, 1997). This science is very important in all aspects of water supply and use. Consequently, the science is valuable in forestry, agriculture and other parts of environmental science (Ward and Elliot, 1995). However, Wisler and Brater, (1959) define it as the science that deals with the processes governing the depletion and replenishment of the water resources of land areas of the earth. It is a science that treats the various phases of the hydrologic cycle because it is concerned with the transportation of water through air, over the ground surface and through the earth strata. Hydrology deals with atmospheric, surface- and sub-surface water.

According to Wisler and Brater, (1959), knowledge of hydrology is of basic importance in practically all problems that involve the supply and use of water for any purposes whatsoever. This implies that hydrology is important in engineering, forestry, agriculture and other branches of natural sciences.

3.4.2. Landfill Leachate and Gas

Generally, the disposal of waste is a potential threat to groundwater underneath the waste disposal facility and the atmosphere (Figures 18 & 20). Dumped solid waste slowly releases initial interstitial water, as well as some of its by-products from decomposition mixes with water that moves through waste (especially from precipitation). Mor et al, (2006) suggest that this liquid is what constitutes leachate, which is the main source of groundwater contaminants from waste sites. Leachate is defined as highly contaminated water that emanates from a waste disposal site (Oweis and Khera, 1995). This accumulates at the bottom of the waste facility and percolates through the soil to groundwater. The nature and concentration of leachate from a waste site depends on waste composition, the rate and amount of water infiltrating through waste to groundwater and the length of time that water infiltrating waste is in contact with the waste (Grover, 2000).

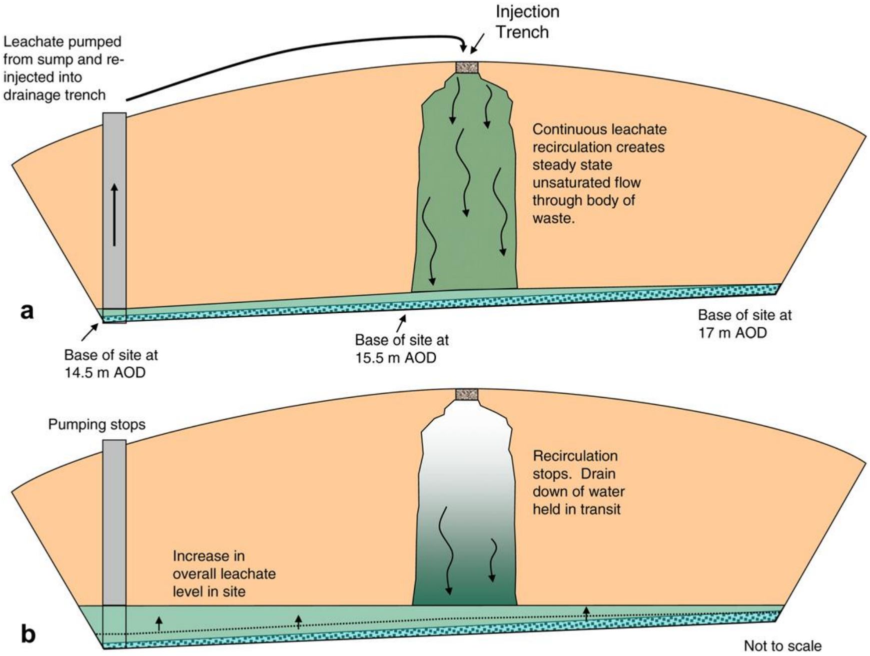


Figure 17: Schematic sketch of Beddington recirculation trial geometry

Source: White et al, 2011

Landfill and waste dump site leachate depend on the kind of waste disposed of at site. Leachate, if re-circulated, may be used to optimise the generation of landfill gas, which in turn encourages biodegradation of the waste by raising the water content and transporting bacteria, nutrients and potentially inhibitory waste products (Fig. 17). Recirculation enhances leachate storage within the landfill and consequently reduces the leachate load on a leachate treatment plant (White et al, 2011). This process enhances the production of a more uniform type of leachate thereby facilitating waste treatment and disposal. It reduces the occurrence of dry spots in the waste and consequently enhances the degradation of all waste. Nonetheless, certain drawbacks include: clogging of sub-surface recirculation systems, excessively high concentrations of dissolved salts which predominantly accept inorganic waste and high levels of leachate in the site (Williams, 2005).

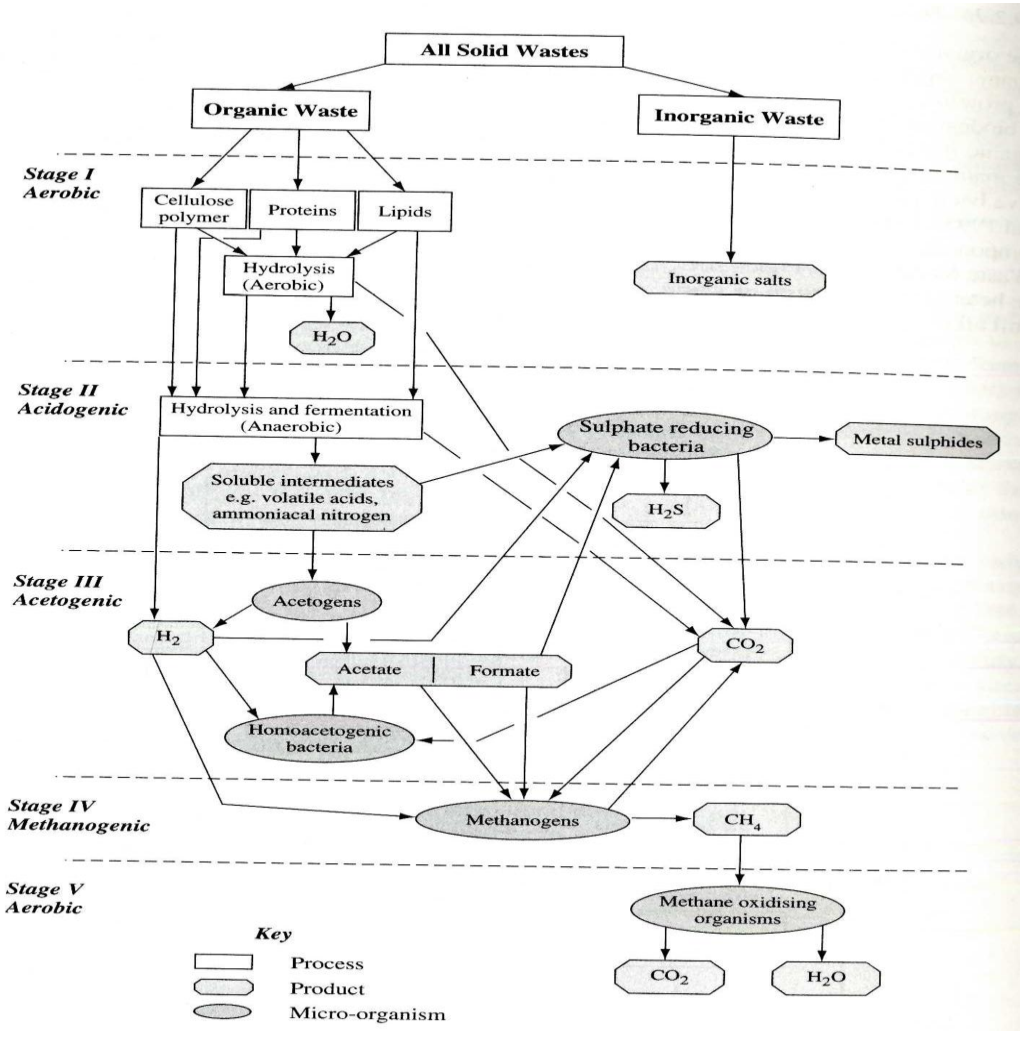


Figure 18: Details of the stages of waste degradation in landfills

Source: Williams, 2005

Landfill gas emissions on the other hand are mainly made of methane (CH_4) and carbon dioxide (CO_2). These gases are the main greenhouse gases that enhance global warming (Figs. 18 and 19). These gases together with other landfill emitted gases are products of both aerobic and anaerobic reaction of waste material in the landfill as in the equations below. Landfill gas can move more than 150m away from landfill (Bagchi, 2004). In Europe the amount of biodegradable waste disposed of in landfill has been reduced by about 65% in order to reduce the amount of landfill gas produced. Germany, for example, produced 40,017,000 tons of municipal solid waste in 1993, 72% of which was biodegradable. Seventy percent of waste dumped in landfills was biodegradable (Williams, 2005).

Aerobic degradation: $C_6H_{12}O_6+6O_2 \rightarrow 6CO_2+6\ H_2O-2.862KJ/mol$

Anaerobic degradation: $C_6H_{12}O_6 \rightarrow 3CO_2+3CH_4$-Energy

Figure 19: Landfill gas composition and landfill gas wells

Source: Voigt, 2010

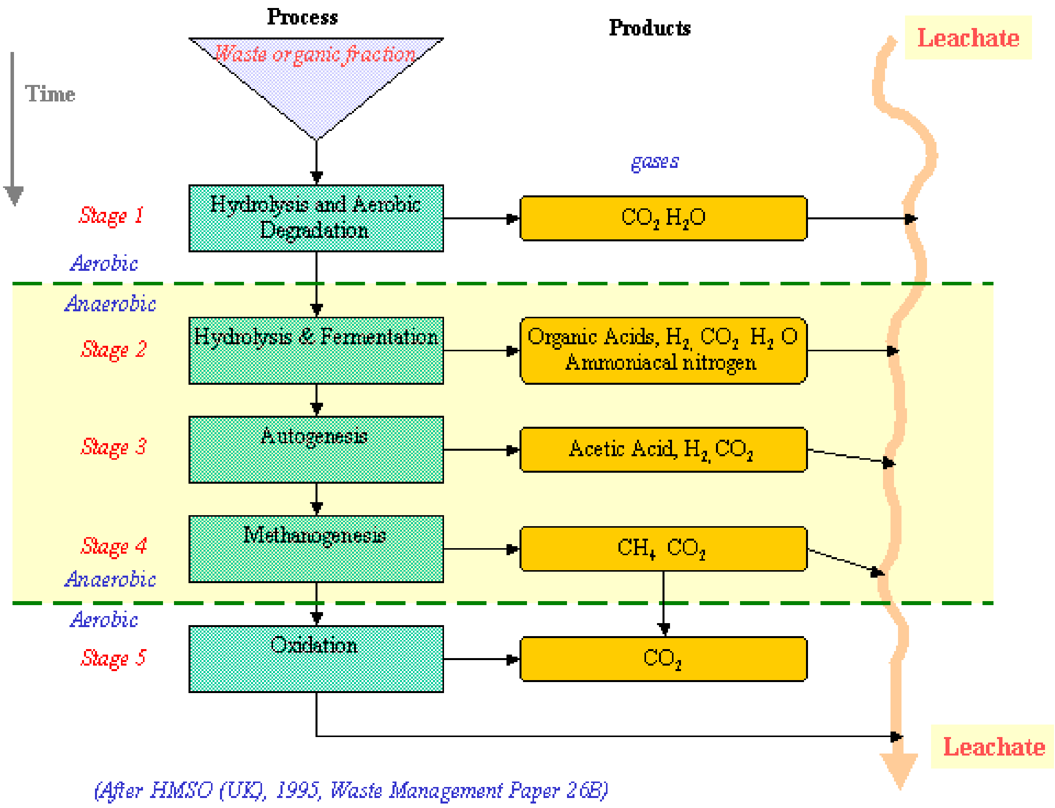


Figure 20: Main stages of waste degradation in a landfill

Source: Associates- the Landfill site, (2011)

CHAPTER FOUR: WASTE MANAGEMENT AND GROUNDWATER IN LIMBE

4.1 Waste Management in Cameroon

Very little research has been carried out in the area of waste management and groundwater contamination in Cameroon. Current research is mostly based on big and prominent cities of the country, like Douala and Yaoundé. Research carried out by Achankeng, (2003) revealed that civilization has contributed negatively to waste generation and management in Cameroon. Waste generation has increased and practically nothing has been done to upgrade the management of this waste and so waste is sometimes littered all over cities. The biggest problem is that waste in cities is managed by the municipality which receives very little assistance from the government. For this reason, and because they are expected to design and implement waste management plans, they find the easiest and most comfortable method of waste management which minimises financial strain. In doing so, they do not take many factors like groundwater, environmental aesthetics and human health into consideration.

Cameroon, like most developing countries, is currently facing relatively high rates of urbanization, estimated at about 4% annually, compared to an annual population growth of about 2.7%. This growth is occurring at a time when the country has been experiencing socio-economic pressures that have led to a decline in economic growth. A serious crisis in financial resources due to a fall in oil prices since the mid 1980s was followed by the National Structural Adjustment Programs (SAP) of the early 1990s. This caused the government to drastically reduce investments and subsidies in the urban sector. Hence, living conditions deteriorated, particularly in the areas of health and education (Manga et al, 2007). Municipal solid waste management has thus been one of the most affected of all sectors.

Poor sanitary conditions in many parts of Africa have enhanced the prevalence of parasites, tetanus, malaria, hookworm, cholera and diarrhoea since waste is littered around cities, villages and other inhabited or settled areas. Incidents of flash floods, water pollution and littered landscapes have also been attributed to poor waste management practices (Manga et al, 2007). In spite of the fact that many factors affect the management of MSW; the population size is also an important factor. The larger the population, the more the problems encountered in waste management. It can be deduced that increasing city size poses more problems in solid waste management in the sense that more waste is generated than can be managed. For example, Yaoundé has a population of about 1.2 million people, and it produces about 1,200 tonnes of waste per day as opposed to a population of 600,000 in the 1960s with 300 tonnes of waste produced per day. The city area also increased from 5000 hectares in 1963 to 20,000 in 2000 and the rate of waste collection has also risen from zero percent in the 1990s to 40-50% collection by HYSACAM (Achankeng, 2003). Previous studies on waste management in Cameroon lay insignificant emphasis on the legislative and regulatory aspects.

However, the Cameroon government created the Ministry of Environment and Forestry in 1992, and also developed a National Environmental Management Plan. In the last decades, ministerial departments have undergone transformation (that is separated or merged) which has enhanced emphasis on waste management (Manga et al, 2007). Though interestingly, no significant emphasis has been made on sustainable approaches to waste management with regard to collection, treatment, disposal and recycling.

Table 12: Roles and responsibilities of key ministerial departments related to waste management in Cameroon

Ministerial department	**Key responsibilities related to waste management in Cameroon**	**Statutory Order**
Ministry of Territorial Administration and Decentralization (MINTAD)	Follow-up and implement regulations for organization and functioning of Councils; Oversees the execution of the budget of the government's council support fund (FEICOM); Restoration of hygiene and public sanitation; Supervises Urban Councils which are responsible for follow-up and control-industrial waste management, management of all public spaces and infrastructure; Sweeping of streets, collection, transportation and treatment of household waste	Circular letter No. 0040/LC/MINAT/DCTD of 04/04/00, Order No. 00072/MINAT/MINVILLE of 21/05/00, Law No. 714/23 of 5/12/74, Law no. 2004/18 of 22/07/04
Ministry of Mines, Industries and Technological Development (MINMITD)	Develop strategies for industrial development and the control of classified and commercial installations for pollution, security, hygiene and industrial nuisance; Define norms for industrial pollution; List of dangerous, obnoxious and polluting facilities in order to inform the public; Develops regulations governing installation and exploitation of facilities classified as dangerous, obnoxious and polluting	Decree No. 99/818/PM of 9/11/99, Order No. 13/MINMEE/DMG/SL of 19/04/77, 02/MINMEE/DMG/SDAMI of 4/01/99
Ministry of Economy and Finance (MINEFI)	Financial control of organizations benefiting from supplementary budgets and autonomous public establishments, i.e. councils; Responsible for managing the finance law as enacted by Parliament	Constitution Decree No. 2004/320 of 08/12/04
Ministry of Urban Development and Housing (MINDUH)	Develops and implements urban restructuring, management strategies, sanitation and drainage; Defines and enforces norms of hygiene/sanitation, collection and/or treatment of household waste; Liaises with international agencies for urban development	Order No. 00072/MINAT/MINVILL of 21/05/00
Ministry of Environment and Nature Protection (MINENP)	Collaborates with other agencies to define measures for the rational management of natural resources; Effective control of investigation and pollution in the field; Specifies the criteria (project specific) and supervises environmental impact assessments	Decree No. 2005/0577/PM of 23/02/05 7], Order No. 006/MINEP of 08/03/05
Ministry of Public Health (MINPH)	Creates Hygiene and Sanitation Units in Councils; Renders technical support to the Hygiene and Sanitation Units of Councils, Proposes norms for collection, transportation and treatment of industrial, domestic waste and emptying of septic tanks; Designs and implements public education campaigns on hygiene and sanitation	Order No. D67/NS/NN/ST/SG/BMPHP/ NNPA of 11/08/87, Circular letter No. D69/N6/DMHK/SHPA of August 1980

Source: Manga et al, 2007

MSW management in Cameroon is mainly co-ordinated by the Inter-Ministerial Commission for Municipal Waste Management in Cameroon (ICMWM), which was created by Prime Ministerial Decree No. 95/230/PM of 30/04/95, and charged with the responsibility to develop policy and formulate appropriate municipal solid waste management strategies. Ministerial departments responsible for the proper implementation of MSW management in the country were assigned responsibilities as shown in Tables 12 and 13 below. A number of key Statutory Orders related to solid waste management were also enacted as seen in both tables (Manga et al, 2007). These roles and responsibilities, and key statutory orders addressed issues concerning waste stream types, environmental and public health protection.

Table 13: Key legislative aspects related to waste management in Cameroon

Legislation	Key elements related to waste management in Cameroon	Statutory Order
Law related to Environmental Management (No. 96/12 of 5/08 1996)	National Environmental Management Plan related to the protection of the atmosphere, marine and continental waters, soils, sub-soils and human settlements; Regulates installations that pose dangers to the public; Stipulates modalities for the conduct of Environmental Impact Assessments (EIA) and categories of operations subject to EIA; Specifies air emission and waste water discharge standards; Sets conditions for issuing authorizations for allotment and management of land for use, i.e. industrial, urban etc, conditions for waste handling (e.g. collection, storage, recycling, etc.), Prescriptions relating to waste elimination by persons producing or treating waste; Stipulates the terms of reference for the supervision of municipal dumps by the competent authorities	Decree No. 2005/0577/PM of 23/02/05, Order No. 006/MINEP of 08/03/05
National Environmental Management Plan	Five year amendable plan; set up environmental information system; Preparation of bi-annual reports on the state of the environment in Cameroon, e.g. identifying problems arising from urban pollution and devising suitable micro-projects to mitigate the problems	–
Law relating to the installation of Classified establishments (Law No. 98/15 of 14/07/98)	Stipulates two types of Classified establishments (Class I and Class II). Dump sites are classified as Class II establishments for which operation and management must follow prescribed guidance. It sets out the regulations governing the installation and exploitation of facilities classified dangerous, obnoxious and polluting;	Decree No. 99/818/PM of 9/11/99, Order No. 13/MINMEE/DMG/SL of 19/04/77, 02/MINMEE/DMG/SDAMIC of 04/01/99
National Water Code (Law No. 98/005/ of 14/04/98)	Provides framework for the exploitation of water resources including waste disposal, Specifies modalities for the protection of surface and groundwater from pollution (including from dump sites).	Decree No. 2001/165/PM of 08/05/01
New Urban strategy, 1999	Partnership among the state, local council authorities and civil society in urban intervention in areas such as solid waste management	–

Source: Manga et al, 2007

The fact is that Cameroon's hierarchy is the top-down system where ministerial departments control the local Councils and the wastage of human and capital resources inhibit adequate and effective implementation of these regulations. Decisions (especially the provision of technical assistance from the government to the local communities) made are usually politically and are not scientifically inclined. Also, political interference limits the efficient delivery and enforcement of available statutory instruments. For example, the duties of undertaking regular visits to waste sites to monitor regulatory compliance is devolved between four ministerial departments (Table 13) and this often results in low levels of enforcement due to a lack of clarity in the definition of responsibilities (Manga et al, 2007).

The waste management legislation in Cameroon has evolved over the last ten years as it encompasses environmental resource protection and the promotion of material conservation through safe disposal and material recovery. This legislation is poorly implemented, especially as the government does not provide mechanisms for effective implementation. Hence, waste management in many Cameroonian cities is centred on the improper collection and dumping of waste elsewhere because it is easy and cheap. This practice conforms to the traditional approaches to waste management in developing countries where cheap solutions are of importance. These practices are related to factors like lack of funding, limited human resource personnel, implementation of inappropriate technologies and relative cost, and political interference (Henry et al, 2006; Manga et al, 2007; Read, 1999; Wilson et al, 2005).

In Cameroon, municipal waste management is the prime duty of Municipal Councils. These are required to provide and maintain waste management facilities like municipal bins, transportation services for waste collection and disposal. Funds used by the Council come from

- Taxes and revenue from council activities
- Supplementary budget from the government through MINEFI
- Lending facilities from Government Council Development Fund (FEICOM) (Manga et al, 2007).

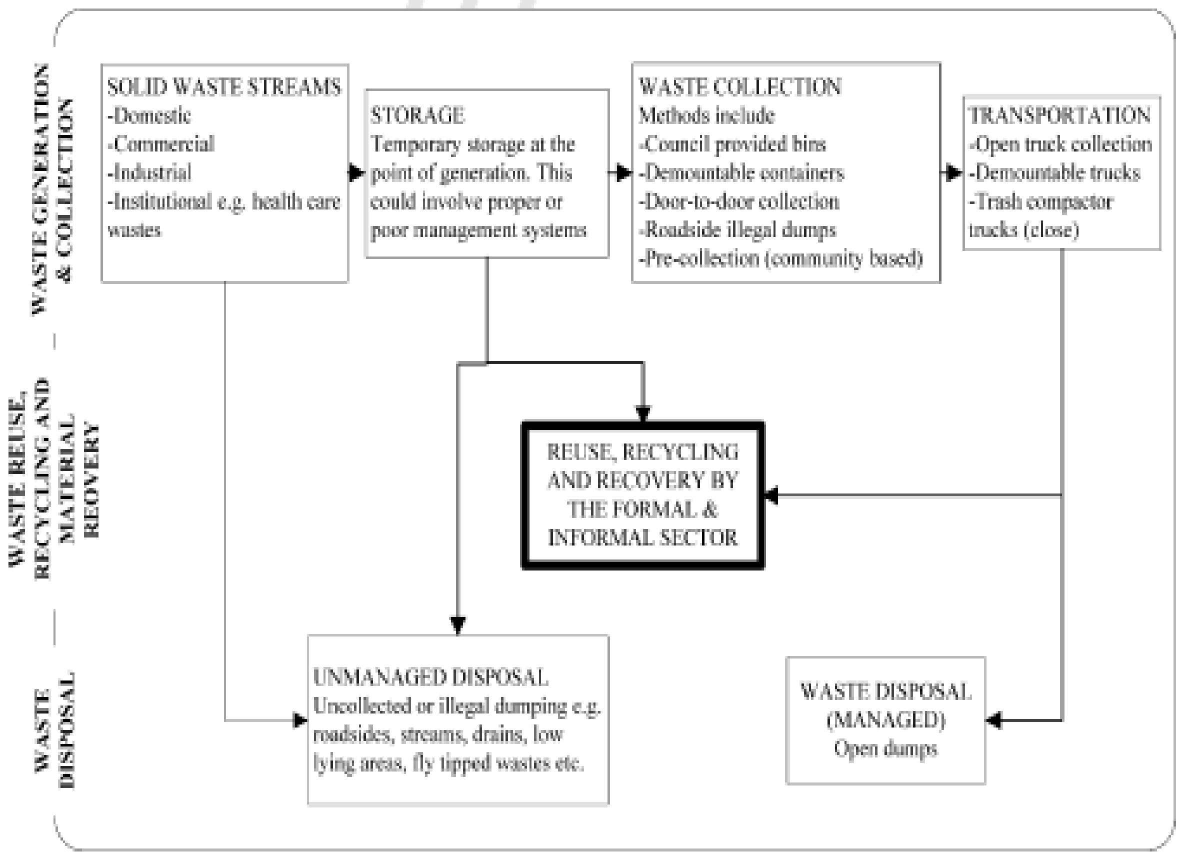


Figure 21: Existing patterns of solid waste management processes in Cameroon

Source: Manga et al, 2007

Waste management related responsibilities are under the jurisdiction of health and safety officers in the Hygiene and Sanitation Units of each Municipal Council. The highest qualified member of staff in each authority is the supervisor who may be a health worker. The Council is responsible for creating and managing these units with partial responsibility for waste management (Fig. 21) or they may subcontract the responsibilities to third parties such as specialized waste management companies like HYSACAM (Manga et al, 2007).

4.2 Environmental Impact Assessment on Waste Management in Cameroon

Environmental Impact Assessment (EIA) is very important in project management. It is very vital in waste management because waste disposal is directly linked to the environment. Very recently, sub-Saharan African countries recognize the importance of the proper implementation of EIA, which can only be achieved through follow-up programmes that actually protect the environment (Ngouana, 2009). In Cameroon, it is important to subject development project to EIA, especially those which could be or are potentially harmful to man and the environment. The World Bank (WB), European Union (EU) and other financial sponsors require all programmes and projects to be subjected to EIA according to the framework law on the Management of the environment (Essam, 2001). After implementation, there should be an EIA follow-up, which will monitor and evaluate the impact of the project so as to know the environmental significance of the project.

EIA in Cameroon is backed by Decree No. 2005/0577 of February 2005 and is made of two types; summary and detailed. EIA reports are forwarded to respective Ministries and the Ministry of Environment. Upon receipt, the Ministry in question sends out a team to verify and gather public opinion and concerns. This group then prepares an evaluation report which is then sent to the Inter-Ministerial Committee (IMC) on Environment, which is also forwarded to the Ministry in charge of the environment. IMC on the Environment involves the Ministry of Environment and Nature Protection (MINEP) and other technical Ministries. The Deputy Minister (Ministre Délégué) of MINEP presides over the Committee (Galega and Neckman, 2011). MINEP then examines the EIA report and notifies the project promoter if this needs correction, has been rejected or accepted. In most cases, if the Ministry stays relatively quiet it means the project has been approved.

MINEP transfers the response to IMC, including the EIA report that has been declared acceptable, the impact study evaluation reports, the evaluation reports and registers of consultations and public audiences. The IMC then gives its opinion on the study of and sends its reaction to MINEP, which makes a decision on the EIA report by granting a decision which is favourable, conditional or unfavourable. An unfavourable condition implies the project must not be implemented and a favourable condition implies the project becomes time-barred if the promoter does not start executing the project within three years.

EIA in Cameroon is similar to that of the Germany, but two aspects are very important, namely, IMC plays a key role in coordinating the process on the Environment, and also provides opportunities for public review and comments on the EIA draft. Public participation (including NGOs) is conducted by MINEP through consultations with the local communities where the project has to be constructed. The public is informed several weeks before the actual date of the consultation, so that they have an opportunity to review the draft EIA draft and to prepare their comments and questions. Public participation in EIA involves a public hearing process that commutes stakeholders, including the neighbouring and affected communities, who understand the social, economic and ecological aspects of the area. The issues raised in the process of public participation are integrated into the project environmental management plan (Galega and Neckman, 2011).

It is important to note that waste management facilities have Environmental, Health and Safety guidelines which include:

- Investigation of geology, soils, ground and water resources of the surface and subsurface will be conducted to determine leachate migration potential and the need for additional design requirements.

- The designing of waste management facilities and access routes to minimize the impacts of waste on air, surface and groundwater, sensitive ecosystems, natural and cultural resources and land-use patterns.

- Gas control systems, if required, will be included in the waste management facilities in order to minimise possible explosions or toxic conditions from the accumulation of waste disposal gas and protect soil-stabilising vegetation (that is, re-vegetated areas along the facilities).

- At the end of each working day, containment cells will be covered with soil or other suitable material so as to minimise odour and prevent scavenging by animals (Geovic Cameroon, 2007).

4.3 Waste Management in Limbe

4.3.1 Waste Composition in Limbe

The amount of municipal solid waste generated in Limbe is estimated at about 7300 tonnes per year, that is, 20 tonnes per day (Awum et al, 2001). This amount is considerably low when compared to that generated in Cottbus, Germany, which is estimated at about 36 million tonnes a year. Limbe has a population of about 120.000 people as opposed to that of Cottbus in 2007 which was 106.415, i.e. 618 persons per sq. km.

The main sources of waste in Limbe include waste from households, industries, schools, hospitals, markets and hotels. The composition of waste varies widely in Limbe as shown in Figure 22. According to Manga et al, (2007), the waste stream is a heterogeneous mixture of materials and products whose composition varies with its sources of generation, as well as the socio-economic classification of the locality.

It is can be seen from Figure 22 that the middle income social group produces higher proportions of biodegradable and plastic waste, probably because of affluence and the increased use of packaged food and materials. This can be associated with the lifestyle and aspiration to be more civilised. Still in this group, a lot of toys and electronic products are thrown. Biodegradable waste contains significant amounts of garden and yard waste unlike the low income community who mostly reuse biodegradable waste for agriculture. Also, the low income community generates more of metal and glass waste like broken bottle, car parts, metal containers, iron and tins. This implies that different types of activities take place here, like the sale of palm oil and kerosene, small shops, bars, mechanic garages and night clubs.

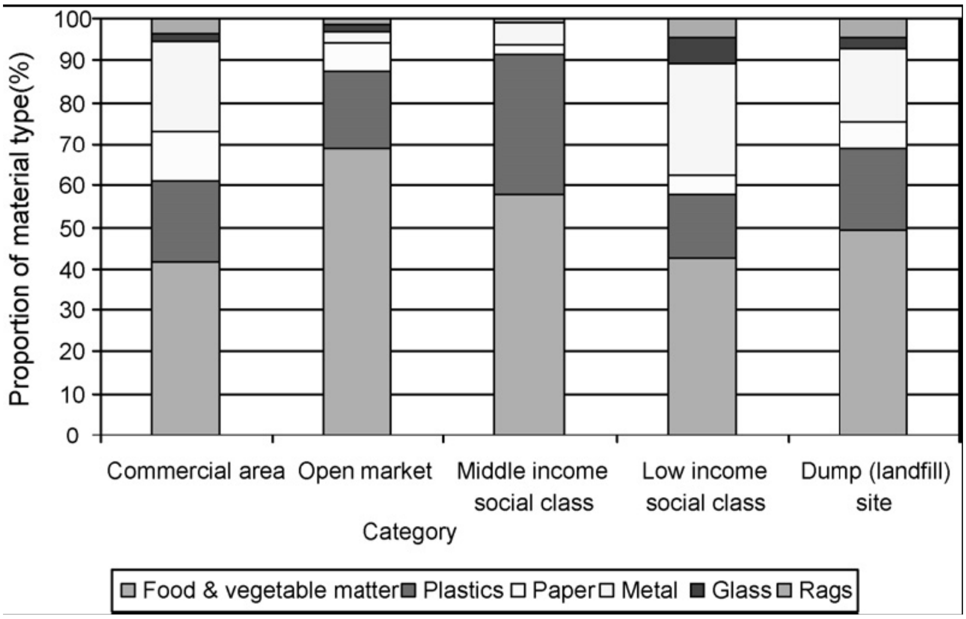


Figure 22: Typical composition of waste from different locations across Limbe

Source: Manga et al, 2007

4.3.2 Waste Management Practice in Limbe

4.3.2.1 Waste Collection Methods

Waste collection in Limbe is not very efficient as the waste collected does not represent the amount of waste generated. The timetable (Appendix 1) provided by the Council for waste collection was not adequately respected. Industrial, hospital and municipal wastes are collected together, implying that no sorting is done. Three forms of collection approaches are used in Limbe, namely; pre-collection, door-to-door and fixed point collection (Achankeng, 2003; Awemo, 2000; Manga et al, 2007).

Pre-collection is the transportation of waste from generation points, mostly by children to municipal waste bins (Achankeng, 2003). This method is encouraged by the Council which has created the first Wednesday of the month as “Keep Limbe Clean” day. On this day inhabitants of the town are expected to tidy their neighbourhood including open dumps so as to ease waste management by the council for sanitation reasons.

Door-to-door collection involves the collection of waste by the council waste trucks. The driver indicates his presence in the neighbourhood, so that people can bring out their waste and throw into the truck. Door-to-door had a fixed program (2-3 times a week) and was carried out in the so-called “High class” areas of the town, like GRA which is easily accessible and inhabited by rich people. The only problem faced here is that the trucks always breakdown and repairs normally take a long time.

Fixed point collection method is the picking up of waste from council bins located at accessible points. This method also has schedules which depend on the popularity and accessibility of the area. In some areas, waste is collected weekly and in others, fortnightly. This form of collection is also impaired by the breakdown of the collection trucks, which hampers collection for up to or more than a month. As a result, waste can stay in council bins for weeks or months and creates situations where people are exposed to waste-associated hazards. Scavengers who visit bins to recover usable waste also scatter waste and ease its access by rats, flies and other organisms.

4.3.2.2 Waste Management by LUC

An interview was conducted with the Head of Sanitations Department in the Limbe Urban Council, Mr. Otto Mussaka. He is the representative of LUC in HYSACAM, who supervises the activities of the company and reports to the Ministry of Environment and Technology (MINET). This interview revealed that a contract was signed in May 2006, handing over the task of waste management to HYSACAM from July 2006. The company had intensified and improved waste management in the municipality which according to future plans would get better. The LUC municipal waste dump site at Mokundange was handed over to HYSACAM as a temporary site. LUC had used it for over ten years. HYSACAM was currently in the process of acquiring a new site at Batoke, since BEAC Bank intended building a Bank complex near the current area.

The Municipal Council, through assistance from the government, finances waste management by up to 85% (an equivalence of about 16million FCFA) annually. There was an evaluation meeting in July 2009 to assess the effectiveness of HYSACAM and create a five-year waste management plan for Limbe. This project goes on in connection with LUC and MINET. The aim of this project was to improve on waste management standards, expand waste collection to small streets and to lay emphasis on public sensitisation.

It was also disclosed that HYSACAM employed 310 workers, 20 of whom cleared the seashore and 10 cleaned in and around the market. HYSACAM also employs seasonal workers for a period of about three months to clean many parts of the town. Sorting is currently not done, but has been included in the plan of action for public sensitisation on sorting from home. The company also distributed blue plastic waste bags to homes for quite some time, but stopped because the Council no longer provided finances for this activity.

At the time when LUC controlled waste management in Limbe, waste collected by the waste collection trucks was transported to waste dumps in Mokundange (Karata) or Motowoh which were built by the Council. The waste was usually dumped for three weeks and then burned. After burning, the waste was then pushed to the back in order to create more space for further waste disposal. From this method of waste disposal, it can be insinuated that the dump sites used were selected and operated with no consideration to human health and the environment. This is shown by the fact that there is no proper monitoring of groundwater, no hydrogeological control and no proper data documentation.

At least six dump sites in different parts of the town have been used by LUC in the last 15 years. Some of these dumps have been abandoned because of increased construction of residential and commercial structures. These sites have not been monitored for post-environmental and groundwater contamination. Therefore, the exposure of the environment and groundwater to contamination could be relatively high. Some of the dump sites were located near farms, plantations, residential areas and streams used by the local people. Some typical examples of council dump sites in Limbe include the New Market and Slaughterhouse dump sites, which are located in swampy areas where flooding is very common in the rainy season. Plates 2 and 3 clearly illustrate that no form of planning was done before site location and waste deposition, especially in the area of groundwater contamination. The water table in this area is very shallow and water in wells sometimes fills up to the surface, especially in the rainy season.

Plate 2: Slaughter house dumpsite in Limbe

It was observed in slums and unplanned settlements that indiscriminate disposal of MSW on roadsides, in streams, bushes, vacant lots and low-lying areas is very common. Flies, maggots and other insects invaded these places which also released odour. This littered waste is carried by rain runoff alongside its maggots and contaminants. Waste is usually burnt in the dry season to reduce volume and create space for more waste. There is no assessment or documentation on this method of disposal on human health and the environment because of poor planning, implementation and lack of human resource development.

Plate 3: New Market dumpsite; waste dumped by the local people with no access to public bins

Plate 4 shows open dumps in different parts of the town which have been created by the local community where waste is rarely collected or managed by LUC. These places normally smell and harbour different types of insects, especially flies and mosquitoes. During the rainy season, these dumps (usually located in marshy areas) can easily cause health hazards, environmental and groundwater contamination because they harbour insects and other unwanted microbes.

Plate 4: Open dumps in slums and unplanned areas created by the local people

4.3.2.3 HYSACAM and Waste Management in Limbe

HYSACAM, Cameroon Hygiene and Sanitation Company, is a French company created in Douala in 1969. It now manages waste in more than ten Cameroonian towns, some of which are Yaoundé, Douala, Sangmélima, Dschang, Bafoussam, Limbe, Buea, Kribi, Mbalamayo, Obala/Sa'a and Tiko. It serves more than 5 million people and has over 200 trucks (80 of which were bought in 2007), which collect over 3,000tonnes of MSW per day.

A discussion with the manager of HYSACAM Limbe, Mr. Michel Ngapanou, revealed that HYSACAM Cameroon signed a Convention with VEOLIA PROPRIETE SA in 2007 to improve on the collection of garbage nationwide. This is a multinational French company with activities in four main areas, namely, water supply and water management, waste management, energy and transport services. This is the 2nd most renowned waste management company worldwide and operates in about 35 countries. The aims of this agreement were to improve environmental conditions by providing waste management services for the residents of HYSACAM towns, and conform to international standards of collection, transportation, safety and waste processing as stipulated by the Kyoto protocol. Both companies work hand-in-hand to continually innovate and optimise the quality of service delivery. VEOLIA also provides the technical know-how to ensure HYSACAM's efficiency, service quality improvement and workers' safety, while closely respecting global standards.

Table 14: Waste collection timetable for Limbe adapted from HYSACAM timetable

Section	Different components	Collection days	Car No.
Section I	Main Road Bota, PMI Road, Clerks Quarters, Down Beach, MOTOMBI Street, Mbonjo Road, Main Street, Church Street, Manga William Avenue, New Town tarred Road	Daily	Camion No. 33
Section II	Mbende, Community Quarters, Gardens, Indian Quarters, G.R.A., Cité Sic, opposite Cité Nanga, SS Quarters	Monday, Wednesday, Friday	Camion No. 05
Section III	Coconut Island, Cassava Farms, Lumpsum, New Town untarred Road, Mabeta New Layout, Mawoh Quarters, Potopto Quarters, Dockyard	Monday, Wednesday, Friday	Camion No. 65
Section IV	Middle Farms, Espoir, Quartier Face Depot Guiness, Comprehensive, Animal Farm-caterpillar Field, Alpha club, Unity Quarters	Tuesday, Thursday, Saturday	Camion No. 65
Section V	Limbé camp, Main Road Mile Four, Mile Seven Camp, Maternity Quarters	Monday, Wednesday, Friday	Camion No. 62
Section VI	Moussoumbou Camp, Samco Quarters, Moliwé, Quarter 14, Quarter 6, Route Bojongo, Wututu Park, Main Road Garden, Inside Garde	Tuesday, Thursday, Saturday	Camion No. 62
Section VII	Batoke, Main Road Batoke, Inside Wovia, Inside Botaland, Isokolo New Road and Old Road, Isokolo untarred	Tuesday, Thursday, Saturday	Camion No.05

Source: Adapted from HYSACAM waste collection plan

Through this agreement, HYSACAM will receive assistance from VEOLIA to carry out waste management through waste treatment. This will enhance the reduction of greenhouse gas emissions like CO_2 and CH_4. HYSACAM also intends to set up compost and biogas collection units. It also plans to intensify activities of industrial and medical waste processing. This will provide hospital and industries with an alternative for processing poisonous industrial and medical waste nationwide (Cameroon News, 2007).

Another interview at HYSACAM in 2009 revealed that HYSACAM was at the end of the first three-year contract which took effect in July 2006 and was preparing reports of the last years. The first evaluation meeting of their activities was due in July 2009.

The company divided Limbe into seven sections and appointed two workers to oversee waste management in these areas. The waste collection plan is done according to these sections (Table 14). HYSACAM has five collection trucks (Plate 5), which include a waste bin carrier, two ordinary trucks and two waste compressors, and a bulldozer to push waste after burning. The company sometimes has to loan another bulldozer from private owners in case of the breakdown of the bulldozer.

Plate 5: Waste site at Karata and trucks used by HYSACAM for waste disposal

There was a plan to close and abandon the current dump site at Karata. Conclusions for the acquisition of a new site at Batoke were to be done by the end of June 2009. According to the contract signed with the Council, only domestic waste should be disposed of at this site. Neither medical nor hazardous waste should be dumped here. But hospital and hazardous wastes are mixed with household waste and dumped at Karata dump site since waste is not sorted (Plates 5 and 8). Waste from the hospital should be treated by the hospital or another company that takes charge of such waste.

The method of waste disposal used by HYSACAM is open dumping and burning. There are two methods of collection;

- Door-to-door collection, which is done by the trucks and waste compressors (Plate 6)
- Fixed point collection

Plate 6: Types of trucks used in waste disposal by HYSACAM

After collection, the waste is taken to the Karata dump site and disposed of. This waste is then either burnt and/or pushed behind, after which it is covered with soil. In the rainy season burning is quite difficult since waste is very wet. So, waste is only pushed to the back and covered with soil. Burning is often easier in the dry season since waste dries up than in the rainy season. There is a lot of smoke and vapour emitted from burnt and fresh waste. These account for gaseous releases to the environment. Some of the plants around the waste dumps may be burnt or may die because of some chemical waste disposal. The waste sometimes already comes with fire which spreads to surrounding plants and area. The people who live in this area say that in the dry season, the waste is also burnt by HYSACAM.

Plate 6 shows pictures of the different vehicles used by HYSACAM. From field observations, it could be seen that some of the cars are old and not well maintained. The workers go about unprotected and hence are subjected to waste-related infections and injuries. Some of them work bare body with no gloves and protective shoes. They also carry or touch waste with their hands. This makes it easy for them to wound their hands and body as the waste which they dump is not sorted and includes hospital and industrial waste components. This is not only dangerous for these workers, but also for the environment. During the research trip of 2009, a worker was killed. He fell from the truck which crushed his head. He was bare-chest with no head protection.

However, information gathered from the local people reveals that the frequency of waste collection and disposal in the municipality has drastically improved since the coming of HYSACAM. Some locally created slums and dumps around Limbe town were properly cleaned. Waste bins were repaired and placed at points which are relatively more accessible to the public. The volume of waste disposed of at the main dump has relatively reduced since most people now reuse some of the waste they generate. According to the Manager of HYSACAM, before taking over the disposal site from the Council, HYSACAM checked on the availability of water around the site and found out that there is practically no environmental and health hazards from the site so far. There exist however, no prove to this claim. Particular and conspicuous areas have been cleaned of littered waste. Areas that are very popular and always visited have been exceptionally cleaned and HYSACAM waste bins provided for household waste disposal (Plate 7).

Plate 7: Cleaning a very dirty, but tourist-attractive area in Limbe (Limbe Down Beach)

- Public sensitisation by LUC. Very few people have adequate waste bins in their homes and children (three out of ten) are often sent to dump waste in the municipal waste bins. This enhances littering waste around the public waste bins. Also, sorting should start at home in order to ease work for HYSACAM workers and ensure proper disposal.
- A commission should be created to map out appropriate criteria for waste collection, which is one of the biggest problems faced by HYSACAM. This commission should involve the Mayor, Government Delegate, the Divisional Delegate for Environment and the Divisional Delegate for Urban Development and Housing. This will enhance a lot of development (road construction and repairs, the creation of new streets, town planning and the demolition of poor structures) for the town to ease waste collection (easy access to waste collection points).
- The management of waste should lay emphasis on the need to prevent groundwater contamination, protection, treatment and monitoring. So far, very little investigation has been carried out on the state of groundwater in this area.
- The proper steps in the construction of a new landfill, must involve barrier specifications; groundwater monitoring before, during and after use, the collection and treatment of leachate, and gas collection, treatment and use.

After the evaluation meeting in July 2009, a new contract (between LUC and HYSACAM) was signed and the company proposed the following strategies for the next project:

HYSACAM has further plans for a proper waste management strategy. The company will improve on its method of communication through more frequent radio and television programmes. They, together with LUC, will produce radio programmes, which will capitalise on small, but important facts like:

- The importance of and how to handle municipal waste properly,
- Types and sorting of waste,
- Types of waste bags (colours) and their use or meaning,
- Waste management in connection with groundwater contamination.

The new site at Batoke had not undergone groundwater monitoring. These analyses would be done immediately after site approval. Water and soil samples would be collected and sent to HYSACAM head office in Douala for analysis. This Unit in Douala does groundwater, rainwater and soil analysis. It also communicates information concerning HYSACAM nationwide.

So far, only two towns have properly built landfills in the country; Yaoundé and Douala. Douala closed the first landfill because it did not conform to the international standards of landfill construction. The second one and the landfill in Yaoundé followed all necessary steps. Preliminary and on-going groundwater monitoring was carried out. There is also an existing policy for post landfill groundwater monitoring. In Douala, a very detailed EIA report was produced before the site could was approved.

4.3.2.4 Problems faced at HYSACAM

HYSACAM encounters the discomfort of trucks and bulldozers breaking down. This affects the work plan and effectiveness of the company. An example was a case in February 2010, when the bulldozer broke down and could not be repaired for almost two month. Waste dumped extended to the road outside the entrance of the site and blocked the road leading to the nearby village (Plate 8). The chief was sent to assist in solving the problem, because the villagers were planning to destroy HYSACAM's property. The Manager pleaded with the chief to give him a little time in order that the bulldozer is repaired. Unfortunately, there was no available bulldozer which could be hired and used during this time. After this dialogue, it took HYSACAM another one week to repair the bulldozer. The manager has applied for the acquisition of another bulldozer so that such a problem could be avoided in the future.

The company also faces problems with the job effectiveness since workers find it hard to adapt to their jobs. The emotional discomfort of workers is one of the major factors that slow work at the company. Workers need psychological preparation programmes which will give them job pride, confidence and assurance. This can be done through training programmes, meetings, workshops or seminars and environmental education on proper hygiene and sanitation. The introduction of incentives, like congratulatory prizes to the best workers, female workers, etc. will make most workers proud of their job. Even though the payment of 60,000FCFA (approx. €90) per month is higher than that of LUC workers, they are still not satisfied. The company also provides a health insurance and covers 80% of the insurance costs and ensures pension for workers (L'actualité, 2007; Mbom, 2006). Limbe was the first and lone HYSACAM Unit so far, where women are employed. Statistics have shown that these women are more confident, comfortable, disciplined and responsible than most of the men.

Plate 8: Waste disposed at Karata dumpsite extending to road leading to Mokundange

An interview was also made with an angry and disgruntled worker who complained that he had been stopped abruptly from work without any notice or reason. He talked bitterly about a very low salary of 60,000 FCFA per month (which is approximately 1,750 FCFA per day). This money cannot sustain his family for one month; yet he has to go to work every day from 6am to 1pm. Workers have worked for at least six months without gloves and dust mask, which implies that they can easily contact an infection. They are forced to carry waste bins (locally called truck pans) on their heads because they have been provided with no waste carriers. Most of them are averagely educated; yet they are treated like illiterates. They do not even have a say to their own rights.

The above problems are very serious and should be given due attention. Measures could be taken to minimise such problems just like the manager proposes. All these plans are included in the agenda and proposals of the evaluation meeting with the council.

4.4 State of Groundwater in the Limbe Municipality

Limbe has very shallow groundwater tables and because it is a coastal town with poor drainage properties, it experiences lots of floods and landslides. This has probably caused changes in the quality of groundwater. Figure 23 shows the distribution of portable water in Limbe.

Previous studies in Limbe revealed that the groundwater in the vadose zone is highly contaminated, especially biologically. The level of microbial contamination is so high that the water is no longer fit for human consumption. *E. coli, Salmonella spp., Bacillus spp., Shigella spp., Neisseria spp. and Staphylococcus spp*. are very prominent in almost all groundwater bodies. Table 15 shows the results of groundwater analysis in Limbe at four prominent areas with the low-income earners. The main sources of contamination include the environment, organic matter, animal and plant waste, soil and faecal matter. This microorganisms should preferably be absent in water samples. Their presence in groundwater is very dangerous to health and can cause diseases like typhoid fever, diarrhoea, dysentery, food poisoning, gastroenteritis and lung infections as in Table 16 (Njabe, 2008).

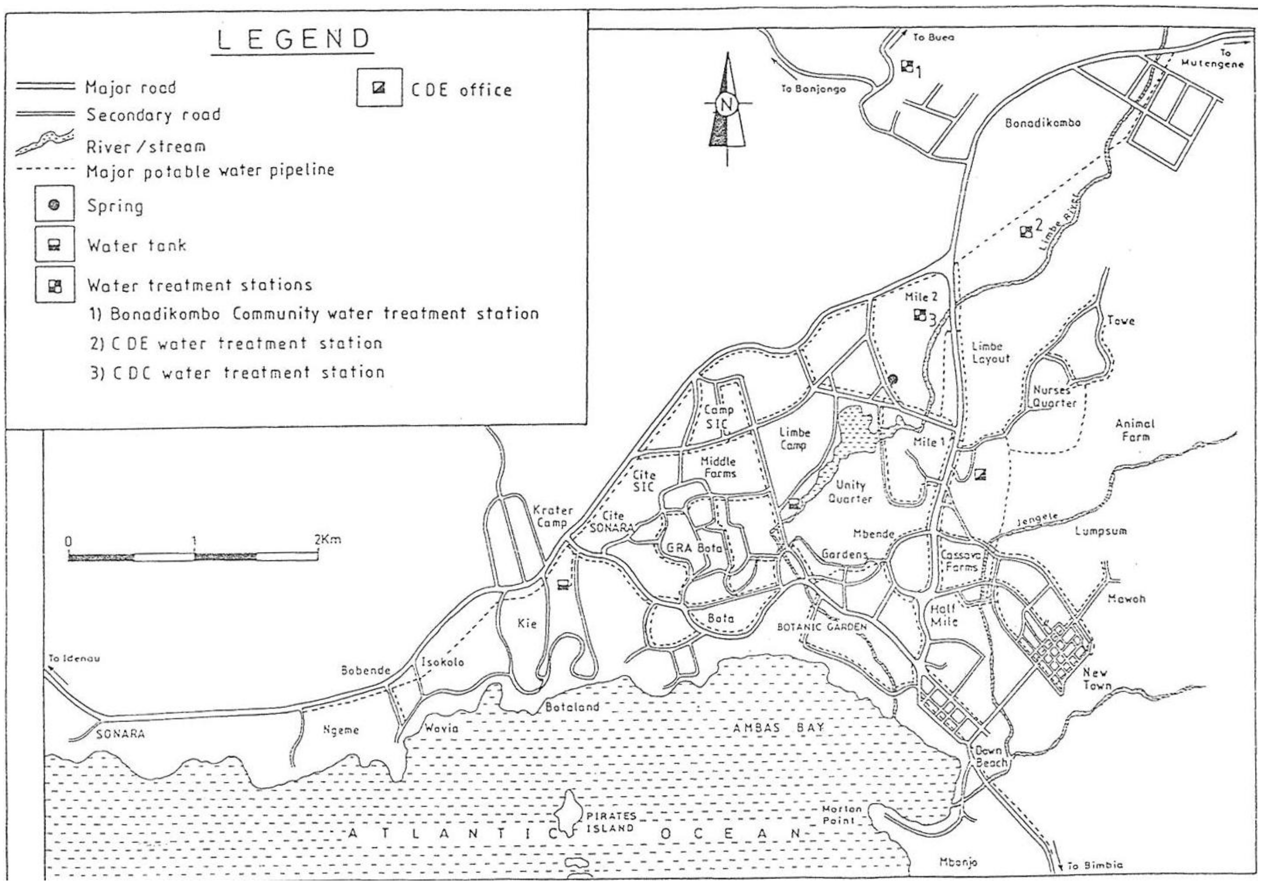


Figure 23: Distribution of portable water supply in Limbe

Source: Adapted from map of portable water network in Limbe SNEC, 1990

Table 15: Microbial analysis of four water samples in Limbe

Code	Names	Observations(TS & TG Broth, sub cultures)	Organisms found
L1	CDC water supply	Slight growth	*Enterobacter spp.*
L2	CDE water supply	Growth	*E. coli* *Staphylococcus spp*
L3	Spring water supply	Slight growth	*E. coli*
L4	Bonadikombi Community water supply	Massive growth	*Shigella spp* *Neisseria spp* *E. coli* *Salmonella spp.* *Bacillus spp.*

Source: Cameroon Baptist Health Board: Central Pharmacy, quality assurance department, Mutengene

Table 16: Water bacteria and the diseases they cause

Bacteria	Water-borne disease caused
Enterobacter spp	Gastroenteritis
Staphylococcus spp.	Diarrhea Toxic shock syndrome
Shigella spp.	Dysentery
Salmonella spp.	Typhoid fever Food poisoning
Bacillus spp.	Lung disease
Neisseria spp.	Meningitis Gonorrhea

Source: Njabe, 2008

The degree of disease occurrence in Limbe compiled from monthly reports from the Limbe health district in 2007 is shown in Table 17. This shows that microbial groundwater contamination has a significant effect on human health. The highest cases of disease were recorded in Bonadikombo. Apart from the state of the groundwater (already contamination) other reasons for disease contraction include; the method of collection and the distance covered after collection. This distance covered exposes the water to environmental contamination. Also, the containers in which the water is collected are sometimes dirty and the handling of food in poor hygienic conditions could also cause water-borne diseases. Cité SIC had the least number of incidences and is inhabited by "high class" people who have access to very good water including mineral water, which they use for drinking and even cooking. The hygienic conditions in "high class" areas are better compared to those of the other areas sampled (Njabe, 2008).

Table 17: The occurrence of water-borne diseases in Limbe

SN	Disease	Total no. of cases	Residence of patience							
			Cité SIC	New Town	Bota Middle Farms	Bonadimkombo	Towe	Gardens	Cassava Farms	Others
1	Typhoid	763	04	42	60	320	72	40	98	111
2	Diarrhea	1123	09	65	77	340	118	111	140	268
3	Meningitis	120	-	03	-	58	05	07	11	34
4	Gastroenteritis	28	-		13	-	-	03	07	05

Source: Njabe, 2008

Physico-chemical analysis of the water samples showed results with values lower than the maximum standards of WHO and Cameroon (Table 18). Total Hardness (TH) fell within the slightly hard range (Table 19).

Generally, water is considered an important natural resource by the inhabitant of Limbe. They know that it is already undergoing contamination and needs treatment. They local people mostly hand-dig wells in the vadose zone. Statistics also show that most people migrate to or inhabit areas where water is available. This can be confirmed from the increasing number of people at water points when there is water shortage. The availability of potable water still remains a major problem (Lambi and Kometa, 2009).

Table 18: Physico-chemical analysis of four water samples

Parameters	pH at 24°C	Parameters (mg/l)						Comments
		TH	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}	
Standard range	6.5-8.5	---	<400	<30	<250	<305	<250	WHO and Cameroon
L1	6.81	98.085	10.009	3.644	Not detected	43.039	38.402	All values are within acceptable range
L2	7.15	109.097	11.010	0.833	Not detected	68.06	29.194	
L3	6.42	98.087	10.009	2.027	Not detected	54.08	32.012	
L4	6.63	112.010	11.010	5.888	Not detected	45.95	49.170	

Source: Njabe, 2008

Impermeable layers of basalt underlie pyroclastic cones and water from the heavy precipitation percolates through scoriaceous material and gets into perched water table (Lambi and Kometa, 2009). High soil porosity is due to the jointed and fractured nature of basalts plus the unwedded nature of pyroclastic deposits. The soil is highly porous and permeable because of loose scoriaceous deposits which have interstitial spaces, cavities and gas vesicles which allow the infiltration of water. It also has impermeable massive basalts which prevent the infiltration of water making the soil impermeable to water and hence the formation of springs.

Table 19: Classification of water hardness

Water hardness (mg/l)	Class
0-50	Soft
50-100	Moderately soft
100-150	Slightly hard
150-200	Moderately hard
200-300	Hard
300+	Very hard

Twort et al, 1974

CHAPTER FIVE: RESULTS AND DISCUSSION

5.1 Field Visit and Observations

A number of field visits to the current and past dump sites of Karata and Motowoh, were made. This was to see the waste disposal method practiced by LUC and HYSACAM, and appraise the factors which were taken into consideration during the selection of the waste dump sites.

5.1.1 The Karata Dump site

The Karata dump (Mokunda Dump) used by HYSACAM is located in the outskirts of the Limbe town, near the Mokundange Village. The inhabitants of this village are referred to as the Mokunda villagers. The dump site has an area of about 120m by 125m, which is about 15,000m^2. The slopes in this area have a steepness of about 30° - 35° in the west, 35° - 40° in the northwest and 70° in the north. There have been no major changes made on the site or method of disposal. The only differences in the case of HYSACAM are that the entrance to the site is guarded; the site is regularly cleaned, and the waste is constantly burnt, shifted and covered with soil.

Plate 9: Method of disposal at Karata; a) burning waste, b) smoke/vapour from waste, c) already burnt waste ready for backward push, d) new waste disposed on cleared area

Information from LUC and HYSACAM about Karata Dump revealed that this is a temporary site which must be evacuated soon. The Bank of Central African States also referred to as Banque des États de l'Afrique Centrale (BEAC) bought much of this area and was due to start construction in 2010. This is located between the entrance to and near the Karata dump. Steps to acquire a new site at Batoke were going on already in 2009.

The method of waste disposal in Karata is open dumping without environmental consideration (Plate 9). Waste is dumped for two weeks, then left to dry and later burnt. The burnt residue is mechanically pushed to the back to create space for further dumping and covered with soil. Covering minimises odour and easy access by rainwater, pests and vultures. In the rainy season, it is difficult to burn because waste stays wet. So, most of the burning is done in the dry season.

Table 20: Total annual rainfall of study area and adjoining regions

Site	Mean (mm)	Maximum (mm)	Minimum (mm)	s.d.	Sample size (yrs)	Maximum expected in 8/10 yrs	Minimum expected in 8/10 yrs
Mokoko	2844	3709	1899	509	12	-	-
Idenau	8392	12449	3303	1866	30	9750	6710
Debundscha	9086	16965	4153	3792	39	-	-
Mokundange	4935	8327	1816	1438	28	6150	3720
Mabeta	4384	6791	1928	1040	30	-	-
Tole	2743	4978	1503	771	30	3291	2112
Molyko	2141	2867	1356	372	29	-	-
Mpundu	2085	5246	438	1033	27	-	-
Malende	-	-	-	-	-	-	-
Mbonge	2192	3102	1475	444	29	-	-

Source: Fraser et al, 1998

The problem of dump sites usually involves the probability of groundwater contamination. The Karata dump area has a number of geological factors which could show partial difficulty for groundwater contamination. The lithology shows that the area is made up of scoriaceous deposits which are underlain by basaltic lava flows (Plates 10a and b). The surrounding hills are also made of scoriaceous deposits, which are permeable and can allow leachate percolation. The area also has volcano-karsts characteristics with a general absence of surface water due to the high degree of porosity and permeability of the scoriaceous substratum.

There are very few water wells and boreholes in the Karata area. The surrounding villages hardly have any source of community water supply. The local people who live in this area say that it is very difficult to dig into the soil and one has to dig very deep in order to get access to available groundwater. This is due to the physiographic and geological settings in the area. Inhabitants depend on pipe-borne water from distal sources for which they have to pay. The volcano-karsts characteristic makes it difficult to get access to water. So whatever leachate is produced seeps down into the groundwater or is washed off by runoff since rainfall in this area is relatively high (>4000mm^3 of annual rainfall as in Table 20). Much of the rainwater rapidly flows as surface runoff, given the appreciable degree of slope between the dump site and the coast. The site is also located approximately 1.05km from the coastline, and there are very few exploitable water sources (wells and boreholes) within this distance.

Plate 10: Waste site, waste types, hills and plants around waste site and waste scavengers: a) Hill around waste, b) Soil in waste dumpsite, c) Plantation and farms around waste and guard's hut, d) Pushed back waste with scavenging vultures, e) Types of waste dumped at Karata, f) Pungent smoke from waste which is choking.

The dump site is also surrounded by trees, grass and some food crops like palm and plantain plantations/farms. These plants are affected by fire from the waste site. There are many vultures scavenging at the site and the road to the site is very poorly accessible. Mokundange village, the Karata CDC camp and Bota Land New Layout are located about 1.0-1.5km away from the site. These people complain of pungent smell and poor roads to the waste site. They feel the waste trucks in particular destroy the road even more. In the rainy season, the area smells more and the waste is sometimes washed from dump site to the road. Another problem is that scavenging birds act as vectors of diseases as they often make repeated visits to residents and the open dump site.

Figure 24 shows the hills that surround the waste dump site showing a horse-shoe formation. The entrance is located to the south of the site, through which waste truck access site for waste disposal. Burnt or old waste is shifted to the north.

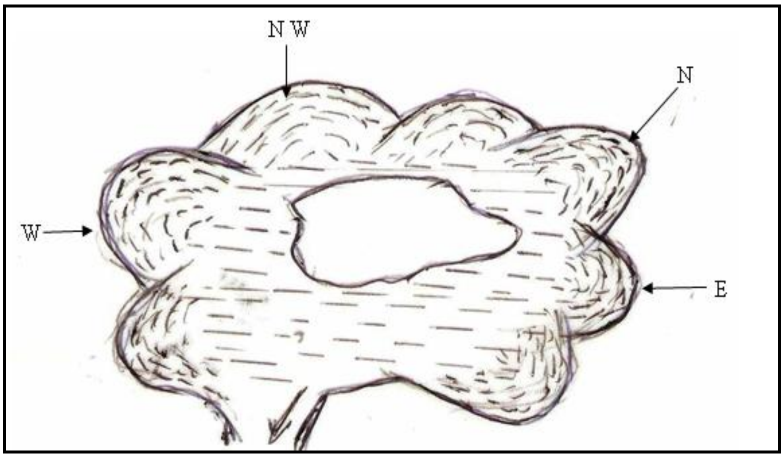


Figure 24: The morphological Settings of the Karata dumpsite ensconced by the horse-shoe string of scoriaceous hills

A topographically low or depression-like structure is enclosed by a number of peripheral hills giving a type of topographic trap. The hills form a horse-shoe formation as seen in Figures 24 and 25. It is indeed a pseudo-intermontane depression, which has been colonised by the municipal authorities.

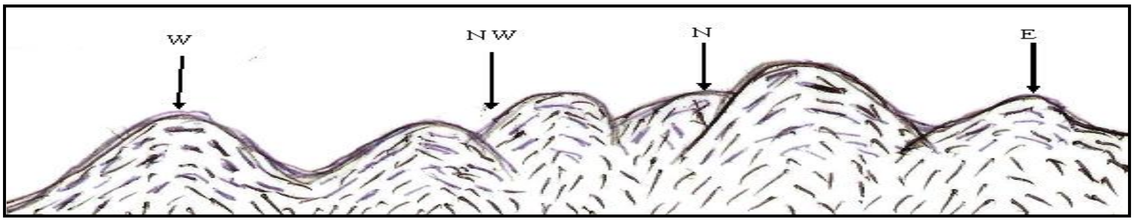


Figure 25: The assemblage of hills that give the horse-shoe formation in Figure 24

Smoke can be seen coming from waste as far as the Karata CDC camp, which is about 2km away (Plate 11). This smoke is a sign of possible atmospheric contamination. This is from burning and decomposing waste processes which release dangerous gases from waste. This gas if collected can be of great importance to energy production for example.

Plate 11: Smoke from farm/plantation near waste. Smoke from waste can be seen from the Karata CDC camp (right) near the road about 2km away

5.1.2 The Motowoh Area and Dump site

Field investigations were also made to the Limbe wetland area called Motowoh. Land reclamation in this area is very poor even though it has a high number of inhabitants. After timid or very little land reclamation, houses were quickly built, and so the marshy characteristics remain with the most significant being the high levels of the water table. The water table in this area is at most 1m deep. In some cases, the water table was less than 20-30cm below the surface or even at surface level. This situation normally worsens in the rainy season during which the area suffers a lot of wetness forming wetlands and swamps.

This area includes the Slaughter House, the New Market and Clerk’s Quarters (Plate 12). Most of the samples were collected in these areas because of their vast and very dirty nature. The slaughter house, for example, is a very conspicuous, but dirty part of the town. Waste generated from the slaughtering process is carelessly disposed of. HYSACAM cleaned the area in 2008, but it still requires proper cleaning and disinfection. Blood and other waste from cattle are left to flow into people's farms while cow horns are carelessly littered around the area. The skin of the cattle is burnt behind the slaughter house as shown in the picture below. All these enhance the release of a very pungent smell.

Plate 12: Slaughter house and New Market dump sites

Wells around the New Market and Clerk's Quarters are very shallow. The water table here ranges between 20cm and 1m below the surface. Some of these wells are built because water overflows the wells in the rainy season (Plate 13). Houses in this area are mostly protected with embarkments, stones, sand, slabs, ground and cement barriers, and gutters. The water table here mostly depends on the altitude of the area. Water here is all vadose water which is very dangerous to health. Substances like plastic and metal containers, electronics, tadpoles and insects are found in the well. The water smells and is coloured. Wells with deeper water tables are cleaner and less pungent. The higher the slope, the cleaner the water is expected to be.

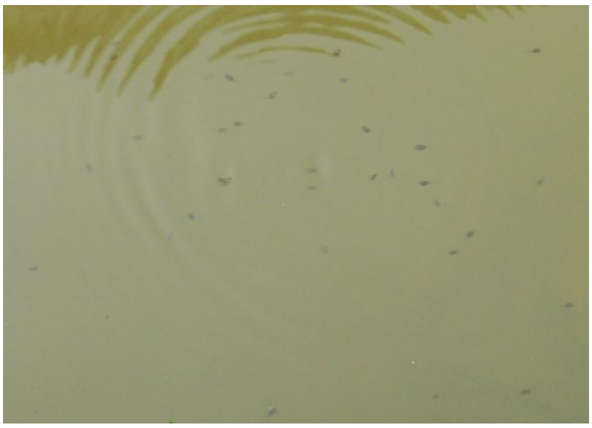


Plate 13: Different wells in the Motowoh area

There is also a cemetery located above Motowoh, the New Town Cemetery. This can be considered a micro watershed because it is more highly elevated than other homes in this area. It is actually located on a hill top. There is a spring located about 3m away from the cemetery, (Fig. 26). Water from this spring is used by inhabitants of this area to wash clothes, clean houses, and flush toilets; but not for cooking or drinking. The soil around this cemetery (Plate 14), that is not elevated, is wet. Almost all homes around this area have dug out wells, with maximum water table depth of about one metre. Water in these wells is very dirty, smells very badly, and should under normal circumstances be avoided. It will be prudent if water from watershed of human remain are not used for fear of possible health hazards from buried corpses.

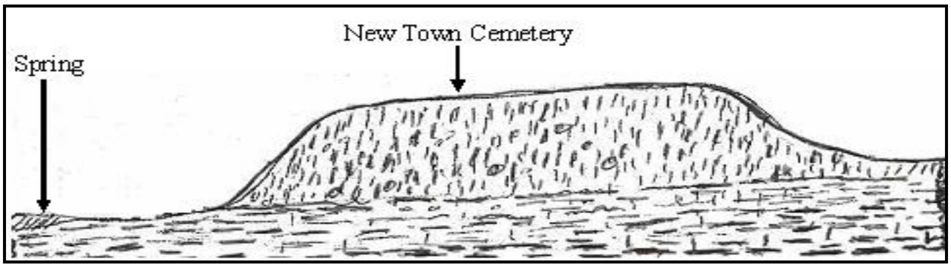


Figure 26: New Town Cemetery (Limbe) with its plateau-like location in relation to the housing located southwards behind it

Most wells contain brownish yellow water. This is probably due to the presence of alluvial deposits from oxidised scoria. The walls of wells are most often green in colour because of the presence of algae and spirogyra. Well water is also grey in colour due to the presence of humus (decomposed matter). Apart from colour, the water always has very strong and disturbing odour probably as a result of high level contamination or pollution. Table 21 shows observed properties in wells in the Motowoh area, some of which were used as sample collection sites for laboratory analysis. Between the months of December and March (dry season) the water table in the Motowoh wetlands is generally very shallow with depths of about 30-60cm.

Plate 14: Spring near cemetery used by local people for washing clothes

A cross-section of the soil was also observed and can be seen in Figure 27. This was done at a building site which had already been dug to prepare for foundation construction. The soil was very wet. The area has very wet soil with scoriaceous, alluvial and iron deposits, clay and silt. The mixed composition of the soil shows man's poor efforts at reclamation of the wetland environment for settlement.

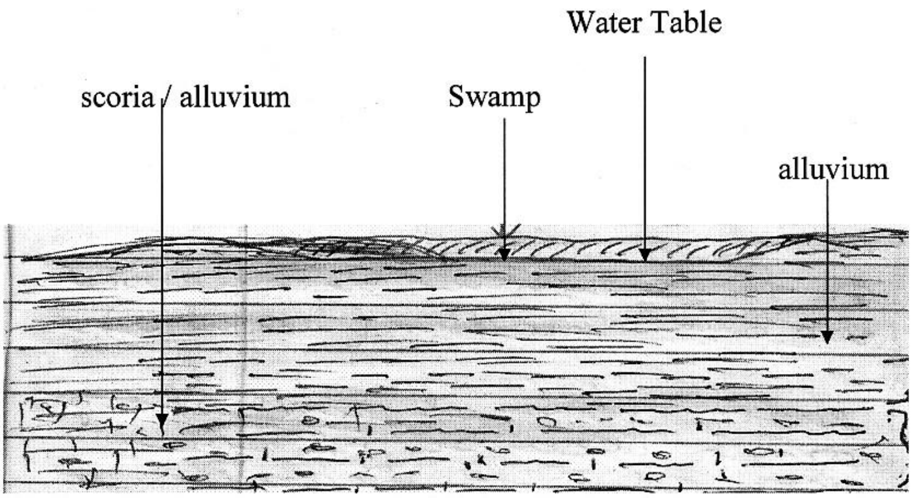


Figure 27: Wetland environment underlain by alluvium and scoriaceous deposits

This area also has elevated foot-hills or hill slope areas, which are inundated during heavy floods with alluvial material and/or scoriaceous deposits (Figure 28). These are underlain by basalts, some of which could be jointed or massive in nature. Wells in such foot-hill locations contain water which is cleaner with little or no odour (Table 22). However, the water table is only some 1-2m deep. All water tables in this wetland area are perched. Hence, water from these shallow wells is used for washing of clothes, the cleaning of floors, washing of cars and flushing of toilets. Water for cooking and drinking is mostly carried from pipe-borne sources, which are sometimes quite expensive and far to reach.

Table 21: Observed data from shallow wells in the Motowoh wetland area

S/N	Depth (m)	Observations
1	0.4	Brownish, significant smell, tadpoles, metals, plants, algae
2	0.35	Grayish brown, pungent smell, plastic containers, etc
3	0.5	Coloured, smell
4	0.6	Brownish yellow, pungent smell, building materials (nails, paint, cement), dead leaves
5	0.3	Green, light smell, algae (spirogyra), frogs and tadpoles, insects
6	0.4	Reddish brown, v. pungent smell, oily, metals
7	0.5	Grayish, no smell, small particles
8	0.45	Reddish brown, tapoles, oily

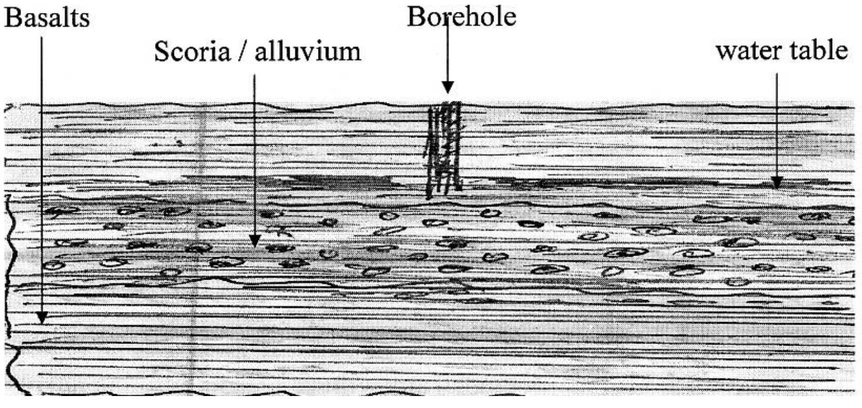


Figure 28: Elevated foot-hill slope areas of the Motowoh wetland environment

Table 22: Deep-well data along foot-hills of the Motowoh wetland area

S/N	Depth (m)	Observed chracteristics
1	1	Dirty water, light odour
2	1,5	Dirty, no odour, plastic bags, metals
3	1,75	Clear water
4	1,5	Partially clear, soil particles, light odour, tadpoles, insects
5	1,8	Clear water
6	2	Clear water
7	1,45	Dirty water, brown colour, metals, plastic bags, dead leaves
8*	1,95	Clear water

* No buildings above well area (no settlement, only light cropping)

5.1.3 Sample Collection Sites

L1: Cold water spring (Mile 2 Extension)

This spring built by the Germans is locally called the German Spring. There are signs of a shift in the source of this spring because of overuse and a drop in the water table (Plate 15). This water, according to some local people, unlike the authority, is boiled and used for cooking and drinking. It is also used for washing as well, irrigation and other household needs. This spring was formerly used for drinking. A tank seen in the picture was used to store water for drinking. Water that did not go into the tank was used for irrigation as this area is also used for plantation purposes and construction (molding of bricks).

Plate 15: The German Spring

L2: Spring (New Town Cemetery)

The spring at the New Town graveyard is more than 50 years old and it is located about 3m away from the edge of the cemetery. The spring has fish, crayfish, spirogyra, fern and household waste. Unlike in 2009, people now stay in house (2010) near the spring (Plates 16 and 17). This is really dangerous because the house already shows signs of future collapse.

Worse still, there are on-going constructions on the other side of the spring in spite of the wetness of the area.

Plate 16: Spring water in February 2009 with one lived in abandoned house.

Plate 17: In April 2010: Inhabitants in abandoned house (2009) near spring and another house undergoing construction on the opposite side

L3: Well (Crab Quarters)

Plate 18: Well that shares boundary with wall of bathroom/toilet

This is a private well used mostly for cleaning, bathing and washing of clothes. There is a bathroom and toilet near the wall where the well is and a pit toilet and farm about 5m away. Water in this well is translucent in colour with a very strong stench (Plate 18). The area is called crab quarters because of a lot of crabs in water around the area. Crabs are also seen in some of the wells.

L4: Well (Community Quarters)

Water in this well is at the surface. This water has colour and a pungent odour. There are also food crops around this well. These include; plantains, sugar cane, lemon (fever) grass, okra and other vegetables as seen in Plates 19 & 20. It is a household well used for bathing, cleaning and the washing of clothes.

Plate 19: February 2009: Dry season yet water is dirty and at the surface

Plate 20: April 2010: After a rainy night, water is very dirty and flows out of the well. Area around well has been cleared for farming purposes and strong winds fell plantain tree

L5: Well beside FATECOL-Motowoh

This family-owned well is well covered, built with cement and used by many people in the neighbourhood because of water scarcity, especially in the dry season. The water is used for cooking as well, especially in the dry season when it is clear. The water is relatively clearer than many other wells in the area (Plates 21 and 22). On the day of sample collection, the water was a little dirty because of heavy rainfall the previous night. This is what normally happens after rains in the rainy season.

Plate 21: Well in February 2009: In the dry season water is a little clear

Plate 22: Well in April 2010: dirty water after rainfall the previous night

L6: Well (Clerks Quarters)

This wetland area with low altitude is always flooded in rainy season. This is one of the dirtiest parts in Limbe. Sea water sometimes floods the area and acts as groundwater recharge. This explains the presence of fish, crayfish and crabs in some of the wells. The whole area smells because of many toilets, animal and poorly dumped (littered) waste. These are located about 6-15m away from the three wells. Houses built here were not planned and people including children also go around bare-feet.

In 2009, samples were collected from two wells and by 2010 one well had dried up (plate 26) and was now used for unsorted waste disposal. There are six toilets (5 pits and 1 flush), one piggery, chicken stall and a farm with food crops (plantain, banana, green and spices), fruit trees (mango, guava and pawpaw) and palm trees (Plates 23-26) in the area. The walls of the wells contain moss, spirogyra and ferns, while well water contains plastic papers and containers, electronics, wooden substances, leaves, fish (from runoff and during floods), tins, peelings (plantain, banana and cocoyam), frogs, tadpoles, dead insects, microbial components (Plates 23 and 24). This water is used daily for washing of floors and clothes, and for bathing. Certainly, this water is totally unfit for cooking. But who knows what the real situation is? The ideology that vadose water is not good may be for such poor people a strange or foreign concept. And for children particularly, water is water and should be drunk if the need arises.

Plate 23: Sample well in February 2009: Few plants, littered unsorted waste, piggery and the closest toilet to this well

Plate 24: Sample well in April 2010 (rainy season) with more plants and dirt

Plate 25: Small exposed well with pit toilet and bathroom very close to it. Water in this well is very dirty with particles, tadpoles and frogs. Well water has a very pungent odour

Plate 26: Well in February 2009 (Lim 8 of samples for analysis in 2009) with dirty water and many particle and same well in April 2010 now dried up and used as a waste pit (almost full)

Plate 27: Waste, plants and animal stalls around wells

L7: Borehole near Karata Dump Site

One very important discovery made during the 2010 visit was a borehole located about 300m away (horizontally) from the Karata dump site at Mokundange (Plate 25). This borehole is owned by a SONARA worker, who distributes water to people in the neighbourhood. It is said to have been dug for two months by Chinese because the geology of this area consists of poorly jointed to massive basaltic flows which were overlain by scoriaceous deposits. The borehole is no longer used for drinking purposes in the neighbourhood because the water is said to have taste, colour and smell. It is now mainly used for bathing and washing of things (excluding kitchen utensils in some homes). Some of the people still use it for cooking and washing kitchen utensils. There is a high probability that the water is contaminated.

Plate 28: View from borehole location. a) Karata dump can be seen from this point. b) Borehole tank which supplies the public with water

There are two surface tanks, each of which carries about 1000 litres of water (Plates 25 and 26). The first tap has a tank about 50m away and was used by the local people. This tap was closed because the local people refused to pay for the up-keep of the tank. This is because they should pay the owner of the borehole for using this water.

Plate 29: Borehole near Karata waste site

The second is located about 100m away from borehole in a house where SONARA workers stay. This is where the water is still used because the water is filtered in a 5µm filter.

Those who use it believe that it is good for consumption because it has no visible colour, taste and smell. Some water sample was collected from this tank for analysis.

5.2 Onsite and Laboratory Analyses

The analysis of groundwater quality is very important to know its suitability for various uses. Groundwater studies reveal that discrepancies in the quality of groundwater in an area are mainly due to the concentration and available physico-chemical parameters, which in turn are dependent on the geologic formation and the anthropogenic activities of that area. These components/contaminants are released from leachate produced in municipal waste, industrial discharges mostly from liquid waste, domestic waste, salt water intrusion, agricultural chemicals and geologic formations (Abdulrafiu et al, 2011; Subramani et al, 2005). Also, the general practice of burning waste is not appropriate because it destroys the organic component in both waste and soil, and oxides metals. Most importantly, landfills and waste disposal sites are identified as major threats to groundwater bodies. Taking this information into consideration, and the fact that waste is haphazardly dumped in the small streets of Limbe, site visits were made in the dry (Dec 2008-March 2009) and rainy seasons, while laboratory analysis was conducted in April 2010 (rainy season) to know how the rainy season affects groundwater. Groundwater samples were collected for microbial and physico-chemical laboratory analysis. It was also observed that most of the people in Limbe depend on groundwater in hand-dug wells, a few boreholes and springs.

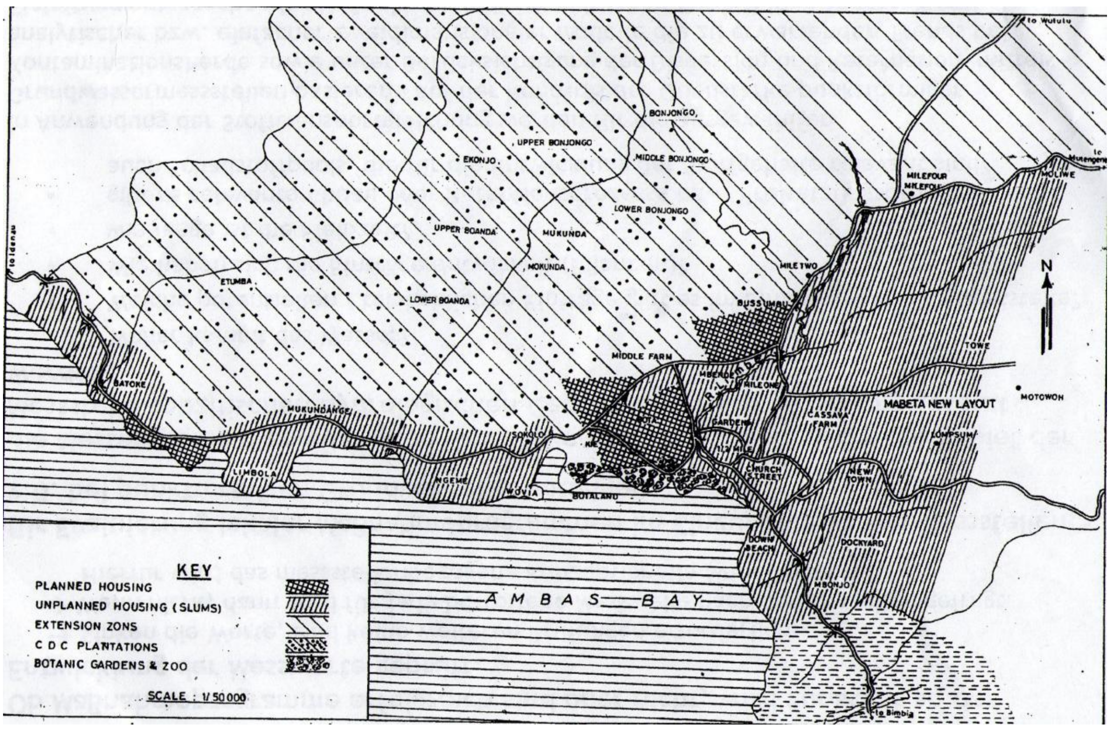


Figure 29: Limbe built-up and extension zones

Source: Awum et al, 2001

Some important on-site tests were made and data was also collected from each sample station. The most important observations made were that the water table drops in the dry season and rises in the rainy season. The rate of this rise and drop in the water table varies for the different parts of the town. Secondly, water in wells and springs is comparatively dirtier and has a relatively stronger odour in the rainy season than in the dry season. The odour in the rainy season is due to the decomposition of waste carried by runoff and littered in the streets. Thirdly, literature on groundwater in Limbe revealed that little or no laboratory analysis or water quality management studies have been undertaken in the area. Lastly, there is currently little or no town planning (Figure 29) in the whole city in spite of the rapid population growth. This has resulted in the building of poorly planned houses, uncontrolled dumping of waste, improper digging of wells, and poor location and construction of toilets and septic tanks.

5.2.1 On-site analysis in Cameroon

Groundwater samples were collected for microbial and physico-chemical analysis. Seven water samples were collected, one borehole, four shallow hand-dug wells and two springs from according to official norms for current Good Laboratory Practices (GLP) at different locations within Limbe Municipality on the 20th of April 2010. This analysis was done between the 21st of April and the 5th of June 2010.

Table 23 shows the sites to have altitudes of 7.0-91m above sea level. Springs and wells in L2, L3, L4, L5 and L6 (Figure 30) have taste and this is probably due to sea water intrusion and high TDS in L6. These shallow wells are as deep as 2.2m (Table 23) because they are locally dug by the people with axes and spades. This is usually very difficult because of the rocky nature of the soil. The higher the altitude, the deeper the water table; and water naturally flows down the slope. This explains why wells at lower altitude contain water with shallow water table.

Table 23: GPS readings taken at various sample sites on April 19th 2010

Code	Site name	Latitude (North)	Longitude (East)	UTM		Altitude (m)
				East	North	
L1	Cold water (Mile 2 Extension)	04° 01' 48"	09° 12' 14"	32 522634	04 45600	50
L2	Spring (New Town Cemetery)	04° 00' 29"	09° 12' 56"	32 523917	04 43008	12
L3	Well (Crab Quarters)	04° 00' 28"	09° 12' 57"	32 523951	04 43002	7
L4	Well (Community Quarters)	04° 00' 21"	09° 12' 53"	32 523851	04 42784	7
L5	Well beside FATECOL - Motowoh	04° 00' 05"	09° 13' 04"	32 524183	04 42294	17
L6	Well (Clerks Quarters)	04° 00' 36"	09° 12' 40"	32 523438	0443240	11
L7	Borehole near Karata dump site	04° 01' 20"	09° 10' 29"	32 519389	04 44585	91

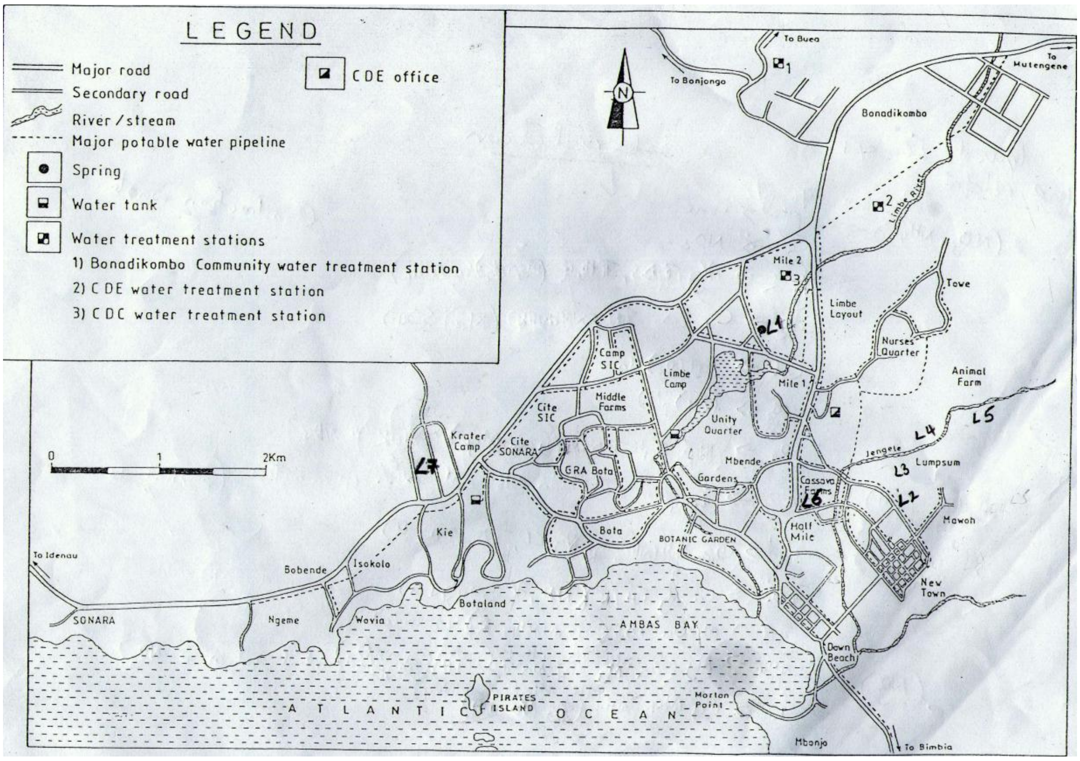


Figure 30: Location of sample collection sites on the Limbe portable water map of Limbe

Source: Adapted from SNEC portable water map of Limbe

The pH is relatively normal for all water samples, except for L2 which has a slightly acidic pH of 5.66. Acidic water is dangerous to man because it leads to ulcers, which when chronic will cause perforation of the intestinal tissues (Abdulrafiu et al, 2011). L2 is the spring near the 50-year old cemetery. It is just about 3m away. Most corpses in Cameroon are treated with chemicals like formalin, formaldehyde, glutaraldehyde before burial. These chemicals could be the possible cause of the acidic water condition. On average a human corpse contains from 55 to 67% moisture, 14 to 24% protein and 12 to 24% fat (Creely 2004). According to Santarsiero et al, (2000) in Creely, (2004), the material of the coffin, packaging, rainfall and topography of area as well as burial practices also play a leading role in the process of decomposition.

Water temperatures at collection point range between 25.6°-31.1°C. The temperature value for water in the German spring (L1) was the lowest (25.6°C). This low temperature is probably due to the location and source of this spring (Table 24). This spring is located at the foot of the mountain and in an area where temperatures are moderately low. L2 shows a temperature of 31.4°C, which is the highest. The decomposition of dead bodies is directly dependent on the environmental conditions of the soil and above ground temperature. High temperatures above the ground increase the rate of decomposition of corpses, but increase in grave depth decreases decomposition rates. This causes the release of gases like aromatic amines, methane and hydrogen sulphide, mercaptans, ammonia and phosphite, which release odour (Creely, 2004).

Table 24: Depth, temperature and pH done on-site (April 20th 2010)

Code	Site Name		Measured Depth (m)	Temperature (°C)	pH
Calibration		*pH 4*		***25.8***	***4.01***
		pH 7		***25.9***	***7.01***
L1	Cold water (Mile 2 Extension)			25.6	6.71
L2	Spring (New Town Cemetery)			31.4	5.66
L3	Well (Crab Quarters)		1.75	27.7	6.51
L4	Well (Community Quarters)		1.30	31.1	7.00
L5	Well beside FATECOL - Motowoh		2.20	29.9	6.30
L6	Well (Clerks Quarters)		2	28.9	6.57
L7	Borehole near Karata dump site		40-60	27.1	6.68

L4 is the shallowest of all wells, with water at the surface. In the rainy season, the water is dirty and smells, as well as it fills up and flows out of the well. Water in this area has one of the highest temperature values with relatively low altitude. This area is also highly populated with temperatures reaching 32°C in the dry season.

5.2.2 Microbiological Analysis in Cameroon

Most wells in Limbe are seasonal wells since they are dug in unconfined (vadose) areas. Unconfined wells are very liable to contamination of all types, including microbiological contaminants. The fact that Limbe has relatively porous and permeable scoriaceous soil makes it easier for microbes from municipal waste to infiltrate into groundwater. Contaminant concentrations vary from point to point and with the activities of the area. All samples showed results higher than the required standards of Cameroon (Table 25).

L7 (borehole at Karata) showed the lowest level of microbial contamination. This is probably due to the altitude, horizontal location of the borehole to the waste disposal site and the depth of 40m. This sample station is located uphill at the foot of the Mt. Cameroon. The borehole is horizontally located to the waste site. Hence, the possibility of waste contaminants to move in the direction of the borehole is low. The disposal of sewage, toilet and household waste could be the main source of contamination in this area. The contamination, even though lower when compared to the other sites, could be as a result of reduced inter-aquifer contamination from unconfined aquifer. Groundwater compounds could also come from natural sources like rock, and volcanic activity. This borehole could be considered the natural groundwater of Limbe, since no data on groundwater was found in Limbe.

Table 25: Results of microbial analysis

Sample code	Organism(s) found	Possible sources	Count (CFU/100ml)	Cameroon Standards (CFU/100ml)	Comments
L1	Total Coliforms *(Enterobacter, Citrobacter* and *Klebsiella* sp)	Faecal matter, soil and sewage	543	<1/250ml	**Results indicate that water sources need to be seriously treated**
	Escherichia coli (E. coli)	Same as above	26	Absent/100ml	
	Staphyloccocus sp.	Skin	24/100ml	Absent/100ml	
L2	Total Coliforms *(Enterobacter, Citrobacter* and *Klebsiella* sp)	Faecal matter, soil and sewage	>1000	<1/250ml	
	Escherichia coli (E. coli)	Same as above	205	Absent/100ml	
L3	Total Coliforms *(Enterobacter, Citrobacter* and *Klebsiella* sp)	Faecal matter, soil and sewage	>1000	<1/250ml	
	Escherichia coli (E. coli)	Same as above	346	Absent/100ml	
	Salmonella sp.	Faecal matter, sewage	103	Absent/100ml	
L4	Total Coliforms *(Enterobacter, Citrobacter* and *Klebsiella* sp)	Faecal matter, soil and sewage	>1000	<1/250ml	
	Escherichia coli (E. coli)	Same as above	256	Absent/100ml	
	Salmonella sp.	Faecal matter, sewage	94	Absent/100ml	
	Faecal streptococcus	Faecal matter, Soil sewage	159	<1/250ml	**Results indicate that water sources need to be seriously treated**
L5	Total Coliforms *(Enterobacter, Citrobacter* and *Klebsiella* sp)	Faecal matter, soil and sewage	735	<1/250ml	
	Escherichia coli (E. coli)	Same as above	102	Absent/100ml	
	Salmonella sp.	Faecal matter, sewage	56	Absent/100ml	
	Faecal streptococcus	Faecal matter, Soil sewage	87	<1/250ml	
L6	Total Coliforms *(Enterobacter, Citrobacter* and *Klebsiella* sp)	Faecal matter, soil and sewage	>1000	<1/250ml	
	Escherichia coli (E. coli)	Same as above	157	Absent/100ml	
	Salmonella sp.	Faecal matter, sewage	102	Absent/100ml	
	Staphylococcus aureus	Faecal matter, Skin sewage	205/100ml	NA	
L7	Total Coliforms *(Enterobacter, Citrobacter* and *Klebsiella* sp)	Faecal matter, soil and sewage	06	<1/250ml	**Water source needs mild treatment**
	Escherichia coli (E. coli)	Same as above	04	Absent/100ml	
	Staphylococcus aureus	Faecal matter, Skin sewage	08/100ml	NA	
	Pseudomonas sp.	Faecal matter, soil, sewage	03	Absent/100ml	

The different microbes found in the water samples include *E. coli*, *Staphylococcus spp.*, Coliform (Enterobacter, Citrobacter, Klebsiella spp.), *Salmonella spp.*, faecal

Strepococcus and *Pseudomonas spp*. These dangerous microorganisms which commonly inhabit the guts of warm-blooded animals and humans are found in bodily waste, animal waste, and sewage or occur naturally in the soil. Total Coliforms, also referred to as faecal coliforms, are bacteria of common (particular) origin naturally found in the soil, and surface water (Vendrell and Atiles, 2003: Water stewardship information series, 2007). They can also exist in the intestines of warm-blooded animals and man, as well as they can be found in bodily waste and animal droppings. These do not necessarily indicate recent water contamination, but can cause very dangerous diseases, especially in people with weak immune system like babies, children, old people and invalids.

Total Coliforms and *E. coli* are important indicators or tracer microorganisms, and their presence in water is an indication of the presence of other harmful pathogens, viruses, parasites and water-related diseases-causing microorganisms (Water stewardship information series, 2007). Diseases and pathogens (disease-causing microorganisms) of contaminated groundwater include;

- Typhoid fever and cholera (bacterial infection)
- Dysentery (mostly from protozoa)
- Polio and hepatitis (viral infection)
- Helminthes like roundworms and tapeworms

Odour, colour and taste cannot be used to confirm their presence in groundwater. According to international standards for drinking water, there should be none of these present in 100ml of water. The value of 10CFU/100ml implies that water is no longer fit for human consumption. It should not even be used for cooking, preparing of raw vegetables, washing of plates, brushing of teeth, bathing and making of ice cubes, ice cream and juice, without treatment. The water must be boiled before use.

E. coli is a member of the coliform group and predominant in the guts (bowels) of warm-blooded animals and man. Due to the fact that it cannot live or reproduce in the environment, its presence in water is an indication of direct and recent contamination of faecal matter, human sewage and animal droppings (Vendrell and Atiles, 2003; Water stewardship information series, 2007). Simple water tests give results of *E. coli* and total coliform, which will imply the presence or absence of disease-causing microorganisms.

Total coliform and *E. coli* were found in all samples, which imply that water is contaminated and needs treatment. The concentrations of microorganisms vary from sample to sample and depend on the activity in the area of collection. L7 is found in an area where people with high living standards live. They have better hygienic conditions with well-built toilets and septic tanks. L1 also has lower values than the other 5 very contaminated samples. This is because it is a middle-class area with more frequent waste collection, minimal waste litter and better hygiene. The other 5 sites (L2-L6) are located in the slums with very poor hygienic conditions, lots of littered waste, open dumps, animal farms and poorly constructed pit toilets. These are in the watershed area of Limbe, with no town planning, which experience flooding, landslides and poor drainage. The main sources of these contaminants include septic/sewage effluents, faecal matter and other waste from toilets, bathrooms, kitchens and gardens. The infiltration of these contaminating microbes is easy because of the soil with scoriaceous deposits, pyroclastic material and weathered basalt which are porous and permeable. Also, household wells are dug in unconfined aquifers with depths of at most 2.20m. All these enhance the percolation of water from runoff, flood water, rainwater, infiltrating water from septic tanks, pit toilets, waste, animal and human faeces. Other causes of water contamination in these wells include:

- Direct contact with surface water, especially during the rainy season when sea water floods some areas
- Improper planning, location and construction of the well. The walls are not built and so water infiltration from other water sources is easy
- Material entering wells from the surface. This is common with uncovered and even partially covered wells
- Shallow well of less than 18m usually have soils that cannot filter contaminants, and all wells except borehole are less than 3m in depth.
- Infiltration from waste water at disposal sites (waste litter and local open dumps)
- Backflow during plumbing, as well as unsanitary plumbing. Because groundwater generally does not contain chlorine, it does not undergo on-site treatment and so artificial treatment is required (Vendrell and Atiles, 2007).

The results in Table 25 imply that intensive groundwater treatment is required, in the areas where L1-L6 samples were collected. This is because they showed very high levels of contamination making it unfit for human consumption. L2, L3, L4 and L6 samples show contamination as high as 1000CFU/100ml of Coliforms, 346CFU/100ml of *Escherichia coli*, 103CFU/100ml of *Salmonella spp.* and 159/100ml of *Streptococcus spp.* These are very high compared to Cameroon standards, which are still higher than international standards. L7 shows very low contamination levels of less than 10CFU/100ml, but still requires minimal treatment and permanent management. According to given standards in Table 25, these groundwater sources are no longer fit for human consumption.

Contaminated groundwater should not be used for irrigation purposes because the crops when consumed may cause pathogenic diseases. Contaminated water with coliform concentration of 200CFU/100ml will infect, for freshwater, 8 out of 1000 swimmers and, in the case of marine beaches 19 out of 1000 swimmers (Vendrell and Atiles, 2007).

Uncovered wells are also very important sources of groundwater contamination. Apart from the wells at L3 and L5 which were partially covered, all other sample wells (apart from borehole) were open and exposed to many types of contamination.

5.2.3 Analysis in Cameroon

The results of physico-chemical analysis in Cameroon are displayed on Table 26 for the following parameters; Ca^{2+}, Mg^{2+}, Cl^{-}, HCO_3^{-}, SO_4^{2-}, TDS, TH, Na^{+}, NO_3^{-}, NH_4^{+} and K^{+}.

This table shows that chemical contaminants are not a major problem in Limbe. This is because Limbe is not an industrial town in a developing country.

Table 26: Results of physico-chemical analysis in Cameroon

	Code	**Cameroon standards**	**WHO (1973)**	**ISI 10500-91**	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**
PARAMETERS (mg/L)	Ca^{2+}	<100	100	75	16.05	20.06	28.08	32.09	24.07	64.19	8.02
	Mg^{2+}	<30	150	30	19.47	19.47	24.33	29.20	17.03	51.10	19.47
	Cl^-	<250	250	250	78.70	39.30	59.00	68.90	59.00	59.00	29.50
	HCO_3	<305			14.01	2.00	22.02	17.02	10.01	10.01	2.00
	SO_4^{2-}	<250	250	200	50.56	36.54	43.68	29.79	16.90	66.87	18.55
	TDS	NA	1000	500	360	284	400	424	376	920	276
	TH	NA	500	300	100.09	78.07	118.11	108.10	68.06	192.17	48.04
	Na^+	<175	200	200	3.80	2.20	2.30	3.00	1.50	4.10	1.70
	NO_3^-	<50	5	45	3.70	37.80	13.80	28.10	28.50	118.10	2.60
	NH_4^+	<0.5			1.90	0.90	1.60	1.80	0.90	2.60	1.30
	K^+	<12			5.30	2.10	5.00	6.00	2.60	13.60	4.70

NA: Not Available

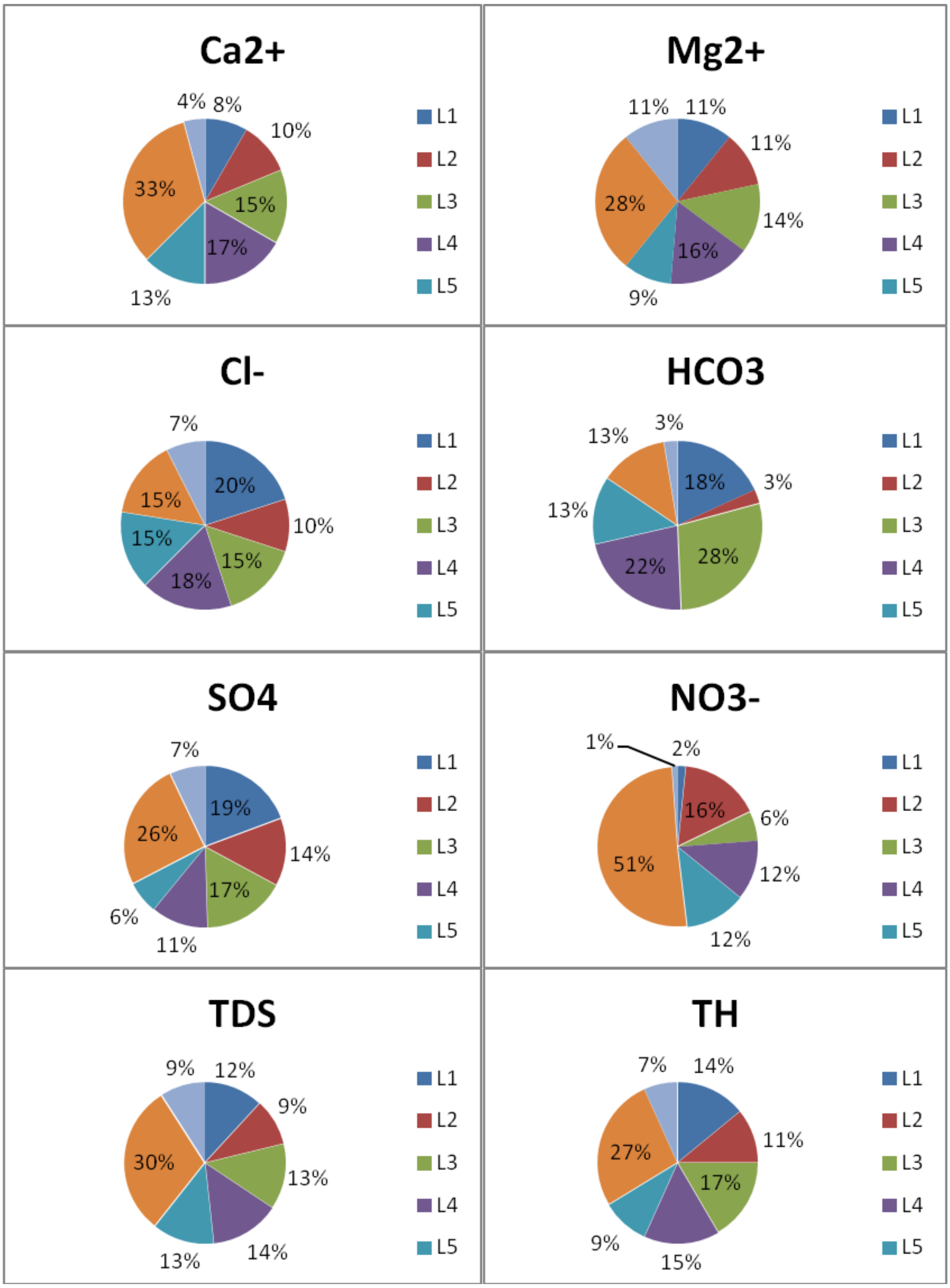
CFU: Colony Forming Units

WHO and ISI 10500-91 standards were taken from Patil and Patil, (2010) and Abdulrafiu et al, (2011). Cameroon standards were provided by the CBC laboratory in Mutengene where analyses were done. Cameroon has no set standards for total dissolved solids (TDS) and total hardness (TH); so the WHO and ISI 10500-91 standards were used.

The results obtained from Cameroon revealed that almost all parameters of physico-chemical analysis did not exceed the required standards. This does not imply that the water does not require treatment. The presence of these chemicals is a sign of mineral chemical contamination which must be avoided. In the case of ammonium (NH_4^+), all samples showed results that exceed the required standards of 0.5mg/L (Table 26). Figure 31 reveals L6 and L4 show high values in almost all parameters measured.

According to Cameroon standards, bicarbonates (HCO_3^-) should be less than 305mg/l. Bicarbonates of calcium (Ca^{2+}), sodium (Na^+) and potassium (K^+) are used to determine the alkalinity of a water body. This is the capacity of water to neutralize a strong acid. Acidic water subjects the human body to stomach ulcers which could, in chronic cases, further lead to intestinal tissue perforation (Abdulrafiu et al, 2011). Potassium is released mainly from weathering of rooks, but high values could be as a result of the disposal of waste water (Patil and Patil, 2010). The values obtained from all samples were mostly extremely lower than those prescribed by Cameroon, WHO and ISI 10500-91. Only L6 showed values (13,60mg/l) of K higher than the prescribed standards of Cameroon. Also, L6 shows the highest values for

Ca (64.19mg/l) and Na (4.10mg/l). HCO_3^- had the highest value (22.02mg/l) in L3 and the lowest in L7 (2.00mg/l) as shown in Figures 31 and 33. L6 shows a good example of potassium from waste water since there is careless disposal of waste water (sewage, washing water, etc.).



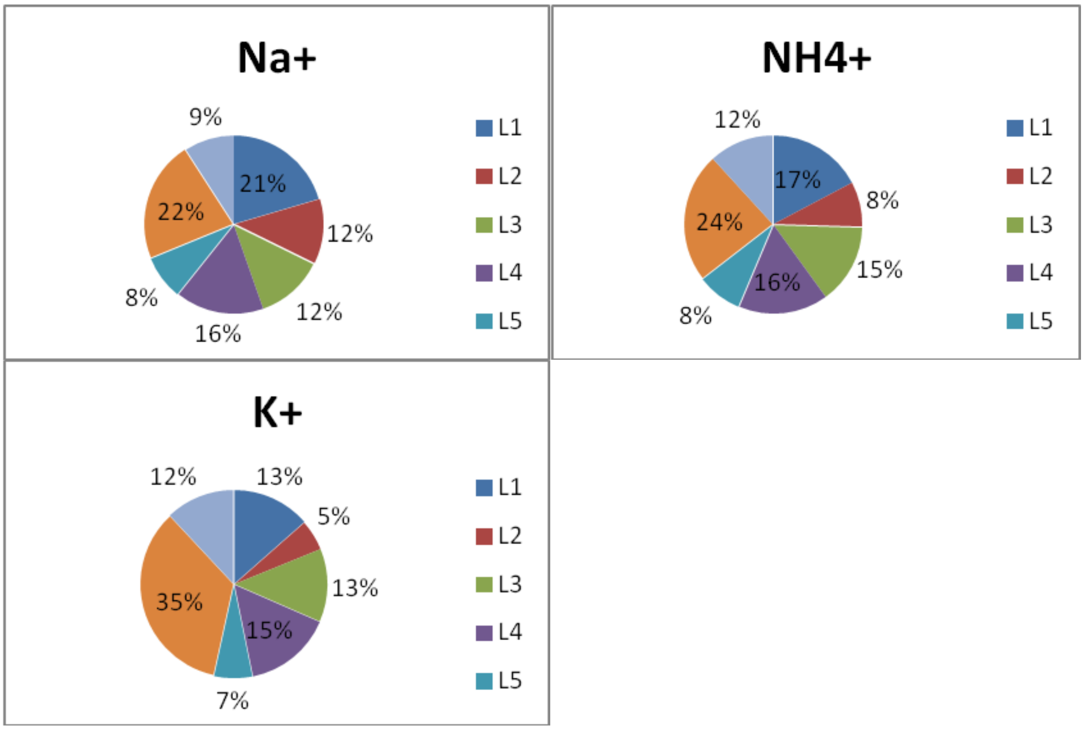


Figure 31: Percentage of each measured parameter at different sample sites

Total Dissolved Solids (TDS) is used to measure the salinity of groundwater (Patil, and Patil, 2010). Oram, (2011) defines it as the sum of anions and cations in water. Hassinger et al, (1994) refer to it as the measurement of the amount of dissolved ions in water. It is an indication for aesthetic contamination, but it does not indicate that the water could cause health problems. It is composed of inorganic salts like Ca, Mg, K, Na, HCO_3, Cl and SO_4. Many of these salts are needed as life-sustaining nutrients. They occur naturally as spring minerals, carbonate and salt deposits, and sea water intrusion. Anthropogenic sources include urban and agricultural runoff, sewage, industrial waste water and chemicals used in water treatment.

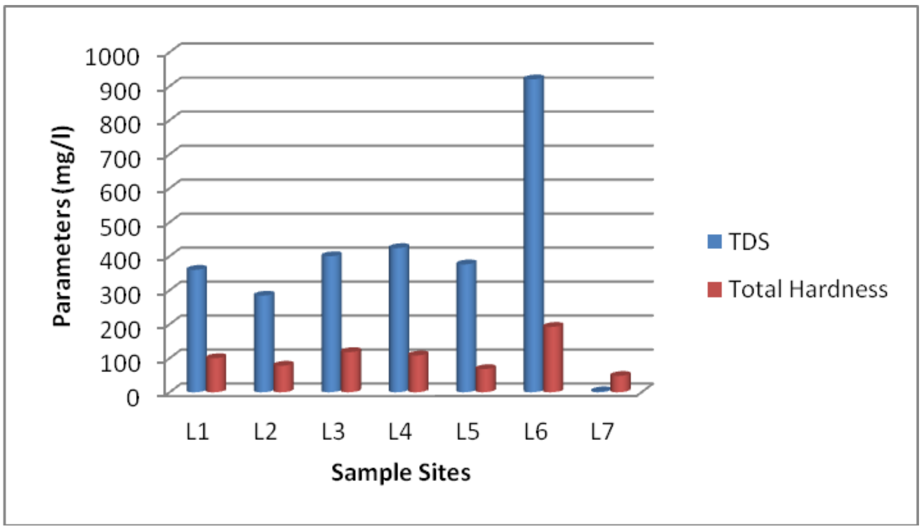


Figure 32: Analysis of TDS and TH

Elevated TDS cause bitter or salty taste of water and also reduces the efficiency water filter and other water equipment. It also indicates the presence of heavy metals like arsenic, aluminum and copper. TDS ranged from 276 in L7 to 920 in L6 (Figure 32). Taking into consideration the altitude of the various sample sites, L7 is highest at 91m above sea level and farthest from the sea, so there is a low probability of sea water intrusion. L6 has the highest value of 920mg/l. This is due to the fact that the area is very flat and only 11m above sea level. It also has very high values for all TDS related salts and has porous soil. The population is very high and land use is varied and uncontrolled. This part of the city is the worst with no planning and very poor waste management. Wells and toilets are constructed close to each other. The very high TDS value could also be because the area always floods in the rainy season, and the presence of many toilets release much sewage.

TDS in L1 is probably due to the mineral nature of the spring. TDS test is only used to indicate general water quality and not specific water quality like corrosiveness. High concentration of TDS could cause health hazards depending on the ions present. If an indicator test shows high concentrations of TDS, specific analysis is then required for each contaminant to determine potential health effects (Hassinger et al, 1994). Nevertheless, the relationship between TDS and water quality can further be understood through the following;

- Cations combined with carbonates, like $CaCO_3$ and $MgCO_3$, which are associated with hardness, scale formation and bitter taste of water.

- Cations combined with chlorides, like NaCl and KCl, which are associated with salty or brackish taste and increased corrosive property.

TDS and TH show a similar trend as seen in Figure 32. Water hardness in groundwater is from weathering of limestone, sedimentary rock and calcium bearing mineral rock. Anthropogenic sources include chemical and mining industry effluents, and excessive application of limestone to soil in agricultural areas. It can also be the amount of calcium and magnesium in water. Total hardness (TH) causes unpleasant taste of waste. Soft water causes pipe corrosion and increases the solubility of heavy metals like copper, zinc and lead. In agricultural areas, it may be used as an indication of sodium from lime and fertilizer (Oram, 2011).

Total hardness (TH) is a water property that increases the boiling point of water and prevents the formation of lather with soap (Patil and Patil, 2010). These would form soap scum which look unappreciable (Abdulrafiu et al, 2011). The values range from 48.04mg/l (L7) to 192.17mg/l (L6). TH most probably depends on the quantity of calcium (Ca^{2+}) and/or magnesium (Mg^{2+}), present in all natural waters, rock and soil. They are both essential to the human body. Magnesium values range from 17.03mg/l in L5 to 51.10mg/l in L6 (Figure 32). Three sample stations have the same value 19.47mg/l. L6 has Mg value exceeding the prescribed limits of Cameroon and ISI 10500-91 (30mg/l), but is within WHO limit (150mg/l). This may lead to gastrointestinal irritation in human (Subramani et al, 2005). Calcium increases bone mass and prevents certain types of cancer, but in high concentrations it may affect the absorption of essential minerals in the body (Oram, 2011).

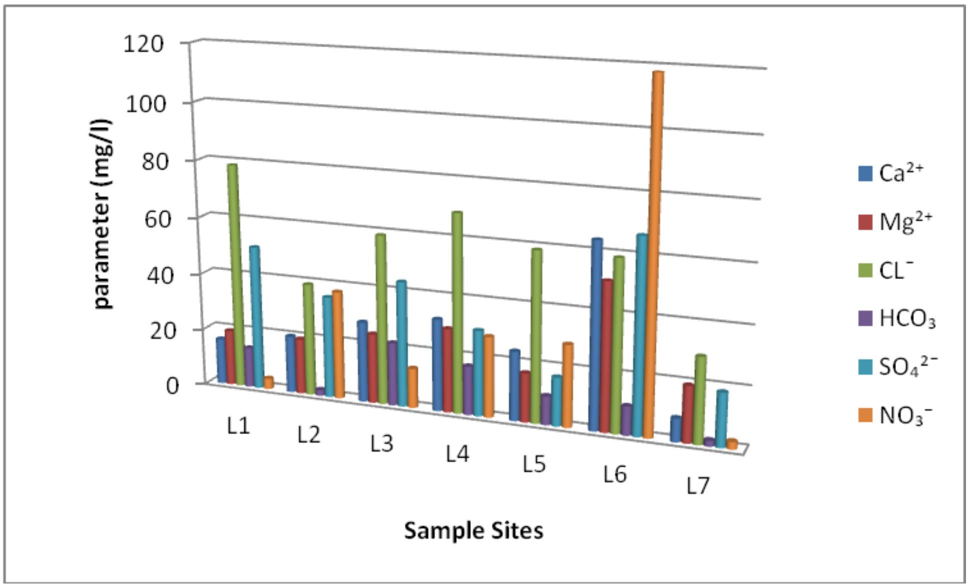


Figure 33: Analysis of Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-} and NO_3^-

Chloride usually acts as an indicator of sewage contamination and their presence in groundwater can cause laxative related problems (Patil and Patil, 2010). It also is an important quality parameter, which affects the aesthetic property and taste of groundwater. In high concentration, chloride makes water unfit for drinking. Chloride concentrations fall within the prescribed limits with L1 showing the highest value of 78.70mg/l. The high concentration of Cl in L1 could be due to the downward flow of contaminated groundwater from the main waste disposal site at Karata, as well as the use of detergents in the spring for washing of clothes. It is located about 3km away and downhill from the Karata waste site. High concentrations of Cl in L4 could be because the well is located near the toilet and acts as a collection point for sewage from the toilet/bathroom of the house (Plates 20-24). According to Abdulrafiu et al, (2011), Cl concentrations above 50mg/l could possibly be as a result of seepage from septic tanks and domestic effluents, like piggery waste, in residential area. This could be true for L1, L3-L6 which are very near toilets and bathrooms. This is because NaCl is a common component in the human diet which passes through the digestive system and into human sewage in the toilets and bathrooms. It can also corrode buildings by extracting calcium to form calcite ($CaCl_3$).

The maximum value of sulphate (SO_4^{2-}) concentration prescribed is 250mg/l (Table 26). All samples show values far lower than this limit. The highest value is 66.87mg/l in L6, and the lowest is 16.90mg/l in L5. The concentration of sulphate increases in areas of high sewage production, but it occurs naturally in areas where gypsum and other common minerals are leached (Patil and Patil, 2010). Sulphate becomes very unstable when it exceeds 400mg/l and it has adverse effects on human, by causing laxative effects (Subramani et al, 2005).

Nitrate is produced when nitrogen is converted, under aerobic conditions, by nitrifying bacteria. It is a major contaminant in water. The major sources of nitrate include agricultural, industrial and municipal waste discharges like septic tank effluents, agricultural fertilizers, animal manure and slurry spreading in buildings (Abdulrafiu et al, 2011; Logan, 1995). It is an anion that is highly soluble in water and very mobile in soil because it is repelled by the net negative charge in most soils. Nitrate does not form strong chemical bonds with minerals surfaces like phosphorous. It is non-conservative, that is, it easily changes form in the environment and moves between the soil-water-air compartments of the earth (Logan, 1995). As a result, it easily percolates the soil in rain to groundwater bodies (Abdulrafiu et al, 2011).

Nitrate concentrations range between 2.60mg/l in L7 and 118.10mg/l in L6. All samples except L6 have values below Cameroon, ISI 10500-91 and WHO standards. Taking into consideration the number of toilets, animal farm and food crop farms around this well (L6), the high NO_3^- value can be expected. The well is not even covered and is found at the centre of all these sewage release points. Plates 20 and 21 show picture of toilets, animal and crop farms. Nitrate is dangerous because it is reduced to nitrite (NO_2^-) by gastric enzymes of humans and animals. This binds to haemoglobin and restricts the transfer of oxygen from the lungs causing the blue baby syndrome, methamoglobinemia and gastric carcinomas. This can subsequently lead to the formation of nitrosamines which may produce carcinogenic cells in adults (Abdulrafiu et al, 2011; Logan, 1995; Subramani et al, 2005).

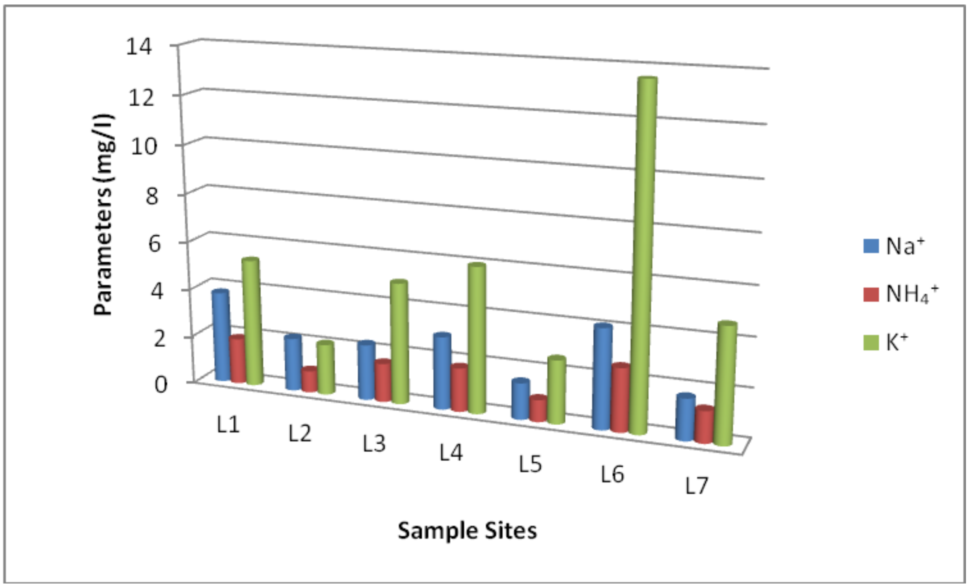


Figure 34: Analysis of Na^+, NH_4^+ and K^+

Ammonium (NH_4^+) is normally produced when atmospheric nitrogen is fixed and subsequently mineralized by soil bacteria (Subramani et al, 2005). It has the lowest prescribed limit for all samples in Cameroon, but all samples show values higher than this limit. L6 has the highest value of 2.60mg/l while L2 and L5 have values of 0.9mg/l each (Figure 34). Possible sources include fertilizer and wastewater disposal. NH_4^+ can also be produced through ammonification where soil nitrogen is used by soil microorganisms as an energy source (Roy et al, 2003). Excess NH_4^+ can enhance bacteria and coliform population increase in water. It can be oxidized by biotic and abiotic reactions to produce nitrite and nitrate, respectively. NH_4^+ concentrations greater than 2.0mg/L require expensive treatment processes to remove nitrogen species from water.

Biotic reaction: $NH_4^+ + \text{Nitrosomonas} + 2H_2O \leftrightarrow 8H^+ + NO_2^-$

Abiotic reaction: $NH_4^+ + \text{Nitrobacter} + 3H_2O \leftrightarrow 10H^+ + NO_3^-$

Ammonification: Soil organic N + Soil microorganisms$\rightarrow NH_3^+ + H^+ \leftrightarrow NH_4^+$

Also, ammonium is one of the main products of nitrogen metabolism in man. It is converted to urea in the liver. This can lead to high concentration of ammonia in the human blood and subsequently liver problems which can cause death (Lockwood et al, 1979).

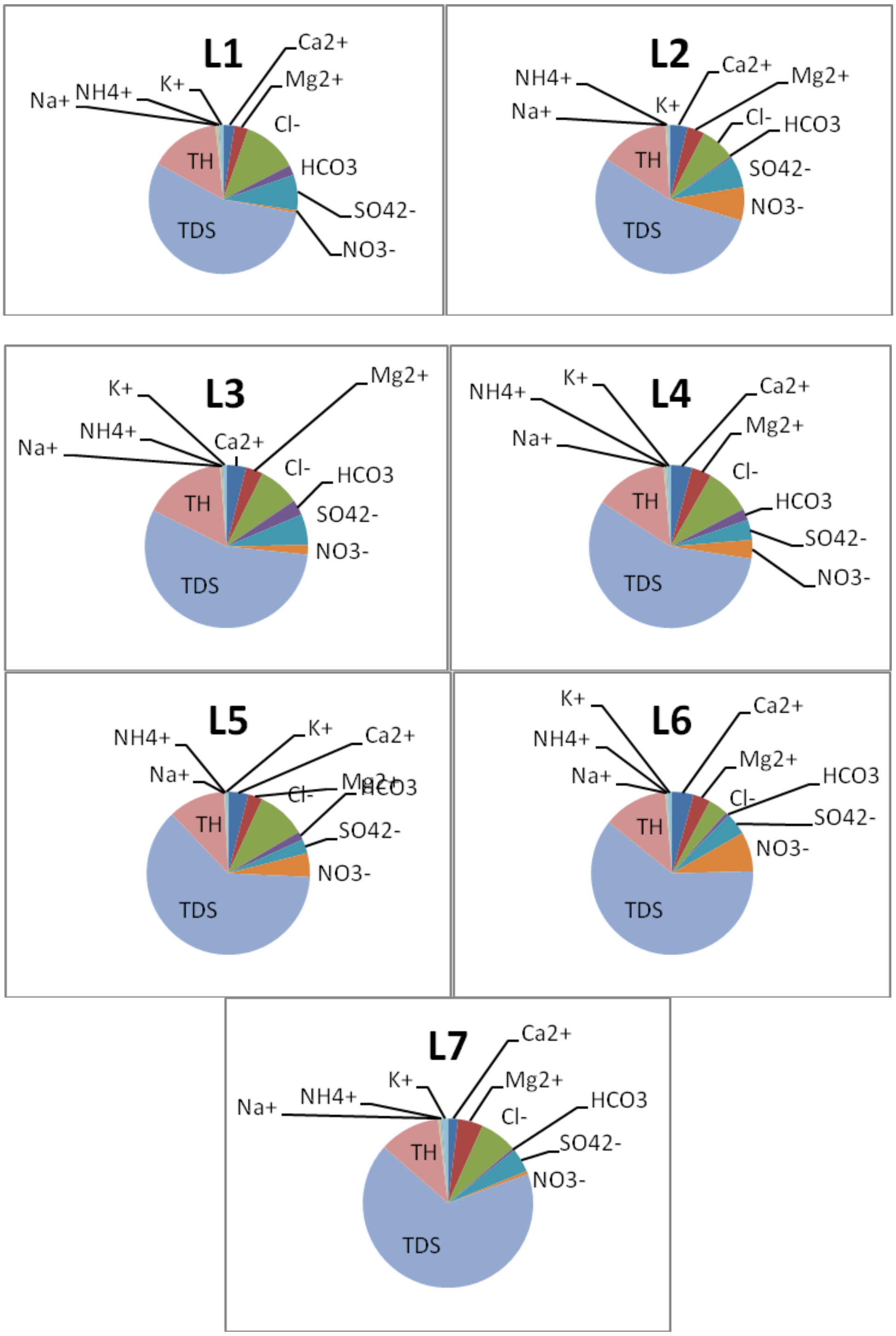


Figure 35: Different sample sites showing the occurrence of different compounds

It can be seen from Figure 35 that total dissolved solids (TDS) has the largest value in all sights. L6 has values higher than the required values of ISI 10500-91 (500mg/l) and lower than that of WHO which is 1000mg/l.

5.2.4 Analysis in Germany

Samples were analysed in Germany three weeks after collection to be able to compare the trend of contamination with samples analysed in Cameroon. Nine out of the eleven parameters analysed in Cameroon were analysed in Germany. TH could not be analysed because the samples were stale and would produce conflicting results. The trend of the results was relatively the same, but there was a great change in values because of the chemical changes which occurred in the samples during storage in and transportation from Cameroon.

Also, electric conductivity (EC), which could not be calculated or measured on-site (collection day) was also calculated. From Table 27, it is seen that the values are either lower (Cl, NO_3, SO_4, NH_4, K, Mg, Ca and TDS) or higher (pH, HCO_3 and Na) than those analysed in Cameroon. Water samples were cooled during storage and transportation to Germany and so temperature conditions affected the sample (from high temperatures in Cameroon and winter temperatures in Germany). Drastic drop in TDS is due to changes in the state of ions especially calcium and magnesium which highly impact TDS and TH.

Table 27: Results of physico-chemical analysis three weeks after sample collection and transportation in Cottbus, Germany

Sample No.	pH	Cl mg/l	NO3 mg/l	SO4 mg/l	HCO3*) mg/L
L1	7,14	1,57	2,06	2,28	117,09
L2	6,22	19,12	35,12	6,35	22,68
L3	7,15	22,23	7,56	10,30	79,81
L4	7,57	13,04	18,55	9,66	98,68
L5	6,73	9,02	24,45	2,70	38,95
L6	7,08	22,06	101,86	12,51	101,82
L7	7,42	1,36	1,07	1,80	64,50

*) charge balance

Sample No.	Na mg/l	NH4 mg/l	K mg/l	Mg mg/l	Ca mg/l	Al mg/l	Mn mg/l	Pb µg/L
L1	12,07	<0,1	3,59	9,55	12,83	<0,3	<0,05	<5
L2	14,47	<0,1	1,41	5,78	9,35	<0,3	<0,05	<5
L3	14,74	0,59	3,56	8,44	16,23	<0,3	<0,05	<5
L4	19,46	0,94	4,21	7,22	17,70	1,15	<0,05	<5
L5	8,58	<0,1	1,73	4,34	11,37	<0,3	<0,05	<5
L6	25,54	1,11	12,04	14,20	30,89	<0,3	<0,05	<5
L7	10,60	<0,1	3,40	4,59	4,49	<0,3	<0,05	<5

Sample No.	EC meas. µS/cm	EC calc. µS/cm	EC error	EC QC WMO-GAW-criteria	TDS**) mg/L
L1	222	167	14,1%	pass	138
L2	218	164	14,1%	pass	136
L3	274	208	13,8%	pass	170
L4	292	226	12,6%	pass	182
L5	173	127	15,4%	pass	108
L6	506	410	10,5%	pass	315
L7	155	100	21,8%	alert	96

**) 0,62*EC

According to analysis in Germany nitrate and potassium showed the same trend in both analyses. L6 had the highest value in most of the elements analysed whereas L7 had the lowest values. The charge of HCO_3 was balanced which led to positive values. However, geochemical modeling (phreeqc), which also considers factors like phase equilibria and pH, did not always converge, and when it converged, carbonate values obtained were below the ones given by the charge balance. The obtained pH was so high, that Iron (Fe) III phase saturation indices calculated with phreeqc was substantially greater than zero. This is a clear indication of Fe precipitation as seen in L4, where a yellowish brown precipitate was observed and so it is assumed that Fe (II) in the original sample was oxidized during storage and transportation. This consideration is independent of charge balance since Fe precipitation is a pH buffering mechanism. The pH was measured so as to balance the charge and L4 converged with phreeqc.

Also, the World Meteorological Organisation (WMO) criteria were applied for (Quality Control) QC. WMO criteria check both charge balance and Electric Conductivity (EC) measured vs. EC calculated from analysed results. All sample except L7 easily passed QC. An error of 21.8% (error) instead of 20% (maximum required) was obtained. The charge could mathematically be violated by bringing EC to 20%, but maintaining QC limits and both calculated and measured EC values were far below WHO limits of 1400µS/cm. TDS was calculated from both the analysed result and measured EC, in which case the conversion factor EC-TDS was used as a plausible check in the range of 0.5 to 0.8. The best fit is normally achieved with an average factor of 0.62, which is plausible for the solution chemistry determined.

Heavy metals usually cause mal-functioning of mental and neurological systems as well as the alteration of the metabolic processes in man. They could induce impairment and malfunctioning in blood, cardiovascular, endocrine, immune, reproductive and urinary systems (Abdulrafiu et al, 2011). Aluminum (Al), lead (Pb) and manganese (Mn) were analysed to determine the quantity of heavy metals in groundwater. All samples had values of Mn and Pb <0,05mg/l and <5µg/l, respectively. Aluminum showed values <0,03mg/l except for L4, which had a value of 1,15mg/l. The values of Pb were within the standards of 0.01mg/l and Mn values were beyond the standards of 0.05mg/l. Manganese usually occurs with Fe and is known as one of the most biogeochemically active transition metals. They both discolour water; Mn causes black and Fe reddish-brown colour in water (Sanga et al, 2006; Tay and Kortatsi, 2008).

5.3 Statistical Analysis

Statistical analysis is very important because it helps in a better understanding of the relation between the analysed variables, how they react to changes and eases decision making. It involves interrelationship between the different variables which enhances research and opens new areas of knowledge (Patil and Patil, 2010). Pearson correlation (r) was used because it enhances an understanding of the strength of the linear relationship between two variables.

Table 28: Pearson correlation (analytical results from Cameroon)

		pH	T (°C)	Ca	Mg	Cl	HCO_3	SO_4	NO_3	Na	TDS	TH	NH_4	K
pH	Pearson Correlation	1	-,410	,129	,266	,472	,521	,074	-,579	,377	,218	,222	,589	,421
	Sig. (2-tailed)		,361	,783	,564	,285	,231	,875	,173	,404	,639	,633	,164	,346
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
T (°C)	Pearson Correlation	-,410	1	,260	,110	-,190	-,180	-,256	,930**	-,250	,040	,006	-,318	-,154
	Sig. (2-tailed)	,361		,574	,814	,683	,699	,579	,002	,588	,932	,990	,487	,742
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
Ca	Pearson Correlation	,129	,260	1	,945**	,299	,260	,699	,066	,598	,962**	,935**	,729	,858*
	Sig. (2-tailed)	,783	,574		,001	,515	,573	,080	,888	,157	,001	,002	,063	,013
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
Mg	Pearson Correlation	,266	,110	,945**	1	,183	,156	,734	-,150	,675	,964**	,924**	,846*	,960**
	Sig. (2-tailed)	,564	,814	,001		,695	,738	,060	,748	,096	,000	,003	,017	,001
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
Cl	Pearson Correlation	,472	-,190	,299	,183	1	,752	,432	-,085	,634	,272	,443	,492	,245
	Sig. (2-tailed)	,285	,683	,515	,695		,051	,334	,855	,126	,555	,319	,262	,596
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
HCO_3	Pearson Correlation	,521	-,180	,260	,156	,752	1	,302	-,120	,322	,172	,411	,401	,174
	Sig. (2-tailed)	,231	,699	,573	,738	,051		,510	,798	,482	,713	,360	,372	,708
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
SO_4	Pearson Correlation	,074	-,256	,699	,734	,432	,302	1	-,300	,875**	,744	,888**	,820*	,760*
	Sig. (2-tailed)	,875	,579	,080	,060	,334	,510		,514	,010	,055	,008	,024	,047
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
NO_3	Pearson Correlation	-,579	,930**	,066	-,150	-,085	-,120	-,300	1	-,327	-,170	-,141	-,509	-,406
	Sig. (2-tailed)	,173	,002	,888	,748	,855	,798	,514		,475	,716	,763	,243	,366
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
Na	Pearson Correlation	,377	-,250	,598	,675	,634	,322	,875**	-,327	1	,661	,787*	,887**	,743
	Sig. (2-tailed)	,404	,588	,157	,096	,126	,482	,010	,475		,106	,036	,008	,056
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
TDS	Pearson Correlation	,218	,040	,962**	,964**	,272	,172	,744	-,170	,661	1	,927**	,816*	,945**
	Sig. (2-tailed)	,639	,932	,001	,000	,555	,713	,055	,716	,106		,003	,025	,001
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
TH	Pearson Correlation	,222	,006	,935**	,924**	,443	,411	,888**	-,141	,787*	,927**	1	,871*	,892**
	Sig. (2-tailed)	,633	,990	,002	,003	,319	,360	,008	,763	,036	,003		,011	,007
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
NH_4	Pearson Correlation	,589	-,318	,729	,846*	,492	,401	,820*	-,509	,887**	,816*	,871*	1	,929**
	Sig. (2-tailed)	,164	,487	,063	,017	,262	,372	,024	,243	,008	,025	,011		,002
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
K	Pearson Correlation	,421	-,154	,858*	,960**	,245	,174	,760*	-,406	,743	,945**	,892**	,929**	1
	Sig. (2-tailed)	,346	,742	,013	,001	,596	,708	,047	,366	,056	,001	,007	,002	
	N	7	7	7	7	7	7	7	7	7	7	7	7	7

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The tailed values communicate if the Pearson correlation is statistically significant. If this value increases towards 1 then the correlation is not clear and must be recalculated. Values less than or equal to 0.05 imply that there is strong statistical significance. For example, temperature shows a very strong correlation with nitrate and the statistical significant value is 0.002. This means that the correlation between temperature and nitrate is clear. This positive correlation implies that an increase in temperature leads to an increase nitrate production. In the case of negative correlations, as one variable increase the other decreases.

Elements like Na, Mg are of nutritional importance since they help in various metabolic activities in the body. Cations like Ca, Na and Mg are constantly involved in Cation exchange processes and interactions with aquifer material (Abdulrafiu et al, 2011). From Table 28, temperature is positively correlated only to NO_3 (0,930), with a strong statistical significant value of 0.002. Calcium is positively related to Mg (0.945), TDS (0.962), TH (0.935), K (0.858) and partially related to NH_4 (0.729). Magnesium is positively related to TDS (0.964), TH (0.924), NH_4 (0.846), K (0.960), and partially related to SO_4 (0.734) and Na (0.675). Chloride is partially related to HCO_3 (0.752) with a statistical significance of 0.051. Sulphate is positively related to Na (0.875), TH (0.888) and NH_4 (0.820), and partially correlated to TDS (0.744) and K (0.760) with a tailed value of 0.047. Sodium is correlated to NH_4 (0.887) and partially to TH (0.787) and K (0.743). TDS is related to TH (0.927), NH_4 (0.816) and K. (0.945) and all with a maximum tailed value of 0.003. TH is also related to NH_4 (0.871) and K (0.892). Last but not least, ammonium is positively related to K (0.929). The correlated variables indicate that they have similar or related sources and/or they easily bond to form compounds, and this eases decision making on waste management and treatment. TDS and TH show correlations with most variables meaning they are affected by their presence. Magnesium and calcium are strongly related with main source being construction waste. Temperature enhances the formation of nitrate by enhancing nitrification and denitrification processes. Nitrate on the other hand, shows negative correlation with most components, even though minimal, which means that it is not related to most of the components. pH has partial correlation with bicarbonate and ammonium meaning their presence may affect the pH of water which is not statistically backed.

Looking at Table 29, measured electric conductivity (EC m) and TDS have clear correlation (1.000) with a clear tailed value of zero. Both variables have almost the same correlation with all. pH has partial correlation with HCO_3 (0.701) and aluminum (0.515). Chloride is strongly correlated with SO_4 (0.875). Nitrate is correlated to K (0.820), Ca (0.811), EC m (0.861), TDS (0.862) and partially with Na (0.783) and Mg (0.694). Sulphate is related to Na (0.883), NH_4 (0.905), Ca (0.827), EC m (0.847), TDS (0.847) and partially correlated to K (0.648) and Mg (0.666). Bicarbonate has only partial correlations with Mg (0.707). Sodium is correlated to NH_4 (0.916), K (0.850), Mg (0.813), Ca (0.889), EC m (0.950) and TDS (0.950). Ammonium has correlation with Ca (0.880), EC m (0.877), TDS (0.876) and partially with K (0.780), Mg (0.703) and Al (0.502). Potassium is correlated to Mg (0,887), Ca (0.882), EC m (0.932) and TDS (0.931). Magnesium is correlated with Ca (0.894), EC m (0.912) and TDS (0.911). Calcium shows strong correlations with EC m (0.971) and TDS (0.972).

In both analyses, some components/parameters show similar correlations with each other and this implies that storage does not really affect this relationship. For example, pH has a partial correlation with bicarbonate; Mg has strong correlation with Ca and TDS is strongly correlated to most components. However, changes in samples in the process of storage and transportation affected the correlation between certain elements. For example, SO_4 is also strongly correlation to Cl, Ca, TDS and EC m; HCO_3 was slightly correlated to only Cl in the fresh and to pH, and Mg, in the stale samples. Nitrate was positively correlated to temperature in the fresh sample and positively correlated to Na, K, Ca, EC m and TDS, in the stale sample.

Table 29: Pearson correlation (analytical results from Cottbus)

		pH	Cl	NO_3	SO_4	HCO_3	Na	NH_4	K	Mg	Ca	Al	EC m	TDS
pH	Pearson Correlation	1	-,327	-,230	,121	,701	,206	,441	,304	,183	,166	,515	,144	,142
	Sig. (2-tailed)		,475	,620	,797	,079	,658	,322	,508	,694	,722	,237	,758	,762
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
Cl	Pearson Correlation	-,327	1	,604	,875**	-,063	,642	,608	,385	,444	,623	,020	,646	,646
	Sig. (2-tailed)	,475		,151	,010	,893	,120	,148	,393	,319	,135	,966	,117	,117
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
NO_3	Pearson Correlation	-,230	,604	1	,633	,079	,783*	,623	,820*	,694	,811*	-,109	,861*	,862*
	Sig. (2-tailed)	,620	,151		,127	,866	,037	,135	,024	,084	,027	,816	,013	,013
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
SO_4	Pearson Correlation	,121	,875**	,633	1	,357	,883**	,905**	,648	,666	,827*	,317	,847*	,847*
	Sig. (2-tailed)	,797	,010	,127		,432	,008	,005	,115	,102	,022	,489	,016	,016
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
HCO_3	Pearson Correlation	,701	-,063	,079	,357	1	,536	,546	,569	,707	,504	,302	,514	,512
	Sig. (2-tailed)	,079	,893	,866	,432		,215	,205	,183	,076	,249	,510	,238	,240
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
Na	Pearson Correlation	,206	,642	,783*	,883**	,536	1	,916**	,850*	,813*	,889**	,335	,950**	,950**
	Sig. (2-tailed)	,658	,120	,037	,008	,215		,004	,015	,026	,007	,462	,001	,001
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
NH_4	Pearson Correlation	,441	,608	,623	,905**	,546	,916**	1	,780*	,703	,880**	,502	,877**	,876**
	Sig. (2-tailed)	,322	,148	,135	,005	,205	,004		,039	,078	,009	,251	,010	,010
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
K	Pearson Correlation	,304	,385	,820*	,648	,569	,850*	,780*	1	,887**	,882**	-,008	,932**	,931**
	Sig. (2-tailed)	,508	,393	,024	,115	,183	,015	,039		,008	,009	,986	,002	,002
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
Mg	Pearson Correlation	,183	,444	,694	,666	,707	,813*	,703	,887**	1	,894**	-,066	,912**	,911**
	Sig. (2-tailed)	,694	,319	,084	,102	,076	,026	,078	,008		,007	,889	,004	,004
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
Ca	Pearson Correlation	,166	,623	,811*	,827*	,504	,889**	,880**	,882**	,894**	1	,158	,971**	,972**
	Sig. (2-tailed)	,722	,135	,027	,022	,249	,007	,009	,009	,007		,735	,000	,000
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
Al	Pearson Correlation	,515	,020	-,109	,317	,302	,335	,502	-,008	-,066	,158	1	,109	,111
	Sig. (2-tailed)	,237	,966	,816	,489	,510	,462	,251	,986	,889	,735		,816	,813
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
EC m	Pearson Correlation	,144	,646	,861*	,847*	,514	,950**	,877**	,932**	,912**	,971**	,109	1	1,000**
	Sig. (2-tailed)	,758	,117	,013	,016	,238	,001	,010	,002	,004	,000	,816		,000
	N	7	7	7	7	7	7	7	7	7	7	7	7	7
TDS	Pearson Correlation	,142	,646	,862*	,847*	,512	,950**	,876**	,931**	,911**	,972**	,111	1,000**	1
	Sig. (2-tailed)	,762	,117	,013	,016	,240	,001	,010	,002	,004	,000	,813	,000	
	N	7	7	7	7	7	7	7	7	7	7	7	7	7

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The prominent problems of solid waste management faced in Cameroon are weak and unspecified legislation, poor town planning, inefficient/inappropriate recovery and disposal practices with little or no groundwater monitoring. Figure 29 (pg 88) illustrates poor town planning practised in Limbe. Most of the town is made of slums which are dirty and inaccessible to waste collectors. Houses are built haphazardly even in watershed areas which are even very dangerous to man. These areas often smell especially in the rainy season. Waste litters area and water is highly contaminated. Waste management until now, has been a failure as waste collection trucks can hardly access these areas because of poor planning, and the scattered location of houses and roads.

More so, the involvement of public-private partnerships, public engagement and training remains a significant problem in waste management. In this study, waste and groundwater management policies in Cameroon with reference to a case study of the Limbe Municipal Council was presented. In Cameroon, several waste management regulations should ensure resource recovery from various waste streams, but the implementation methods are severely lacking. Hence, there is an urgent need to improve and/or develop sustainable waste management, through consensus building, consultation, encouragement and openness prior to maximizing the potentials available for waste reuse, recycling and recovery Despite governmental efforts to create and implement legislation related to sustainable waste management and environmental protection, the current policy framework is not efficient.

An inadequate legislative framework and indifference in EIA in Cameroon explain the lack of effective engagement of industry, commerce and the general public in more sustainable waste management practices. In Cameroon and Limbe Municipality in particular, this would suggest the need for the implementation of more robust measures including learning from examples of best practices from other developing countries. However, there would be the need to adapt and customize these best practice principles for an environment specific to Cameroonian towns and cities. Such measures will guarantee the active engagement of all stakeholders and hence, ensure the successful delivery of sustainable waste management practices.

The method of collection and transportation of waste is acceptable according to international standards. Some impediments include poor access to collection sites and constant breakdown of waste collection trucks. Yet, the method of disposal is not acceptable and has already exposed the environment and man to adverse conditions. Open dumping and uncontrolled burning of waste is not appropriate, especially because it brings odour, pests, microorganisms and scavengers to the Karata waste dump. Farms and plantations around the waste site are affected by fire and smoke. It should be noted that at temperatures less than 800°C plastic waste produces dioxide which results in air pollution. Also, microorganisms and bacteria which help in waste decomposition and leachate breakdown. Nevertheless, some of the killed bacteria are dangerous and so are eliminated from waste, as well as organic substances are reduced in the course of burning. This also reduces moisture content and weight of the waste, hence minimising groundwater and soil contamination.

The covering of waste after mechanically pushing to the back is advantageous in that it minimises the release of odour. However, in the rainy season, waste is not burnt and the odour released from waste reaches neighbouring residential areas like Mokunda village and the Karata CDC camp. Shifting waste manually does not minimise the effect of waste on the environment. There is no artificial barrier and no effective measures were taken during site selection. Site selection did not involve EIA and appropriate project implementation especially with respect to the state and depth of groundwater. No landfills have been constructed to enhance sustainable waste disposal to prevent contamination. In spite of these emissions, groundwater monitoring before and during the use of the waste site is not done. The geology of dump site shows that the site has scoriaceous soils which are permeable to water. There is also no documented data on the geology or groundwater condition of the area. Also, waste dumped here is not sorted, implying that clinical, industrial and municipal wastes are jointly dumped.

There was no opportunity to access data on drinking water in Limbe as well as no way to analyse its quality. There was also no means to collect groundwater samples from Karata waste site because there is no well at the site. As a result, water analysis for this study was based on existing local wells, springs and a private borehole. Attempts to rent an equipment to dig a borehole at the Karata dumpsite proved futile as a fee of 6 million FCFA (approximately €9000) only for renting the equipment was requested by the state department in charge of borehole construction in Limbe. Sample results mostly showed physico-chemical values less than those of prescribed standards while microbiological values all exceeded given standards. It can therefore be concluded that L1 (German Spring) and L7 (Borehole) can be considered natural groundwater because they were the least contaminated. They can be used as a basis of comparison for different contamination since they very minimal values. Both samples showed results that are typical of basalt rocks because the value of magnesium was higher than that of calcium. Such soil conditions are good for landfill construction.

Ammonium (NH_4^+), unlike all other parameters showed results with values higher than prescribed standards. Considering that ammonium can cause liver problems in man, serious groundwater treatment is required. Treatment of water with NH_4^+ concentrations exceeding 2.0mg/L (like L6) is very expensive. L6 (Clerks Quarters) showed higher concentration in almost all parameters, a clear indication of sewage water. This is a very dirty and unplanned wetland area which undergoes frequent flooding in the rainy season. Most of the people who live here are poor and build wooden houses. The collection of waste from this area is irregular, so waste litters the area and smells. Accessibility to the area is also impeded by poor roads and the haphazard location of houses. In the rainy season, the roads are very muddy, slippery and consists water-filled gutters (drains). In the rainy season shallow pit toilets and wells overflow enhancing contamination as rain water washes substances into the wells carrying contaminants from different sources. Some of the wells have a lot of particles (batteries, metals, plastic, wood and others) in well water which are also sources of contamination. This area should be considered a risk area because of its geological, groundwater, environmental and social conditions (careless building of houses, poor toilet construction, poor hygienic conditions, etc.). As a result, the area should be evacuated and used for other purposes like a recreational, protected or conservation area.

In Cameroon and Limbe in particular, water related problems usually result from the fact that some areas have too much water manifested as floods and poor drainage, while others have too little water which dries up in the dry season or too little water due to contaminated water which is unfit for human consumption. Microbial analysis of water samples showed very poor results, which implies that the water is not fit for human consumption. Therefore water must undergo immediate and intense treatment before use even for bathing and washing of clothes. Very little or no concrete data exists on groundwater in the Limbe municipality which makes it very difficult to know the original state of groundwater in the area. For this reason, L7, which showed lower contamination levels, can be used as the “natural” groundwater.

The main source of microbial contamination in Limbe is sewage, since almost all samples showed high values of sewage related contaminants. People mostly use pit toilet and have animal farms around wells, which are all major sewage input sources. It will be most appropriate if these water resources are no longer used for household purposes even though pipe-borne water in Limbe is either too expensive or rarely available. Contaminated waste- and sewage water collection and treatment should be the responsibility of the state. Effective management of drinking water must permanently include sewage water management. In Germany, for example, there is a law which obliges citizens to dispose of sewage in the central sewage tank or make provision for sewage collection by the state. This is not the case in Cameroon and Limbe in particular. Sewage collection and treatment should be considered and included in water management in Cameroon and Limbe in particular.

The people of Limbe are conscious of the consequences of poor waste management and groundwater contamination. They are however, not aware that they have already contaminated the groundwater they use. This is because the Council and HYSACAM do very little on the state of groundwater in Limbe and do not inform them of the dangers they are faced with. This incompetent and ineffective part played by LUC and HYSACAM encourages the local people to poorly dispose of waste and continuously use contaminated water resources. However, both agencies are faced with the problem of inadequate human, technical and financial resources. They therefore, indulge in the cheapest possible method of waste and groundwater management, with little implementation of methods that are sustainable to man, groundwater and the environment.

It can be concluded from the state of Karata and New Town Market waste sites that the latter did adversely affect the environment more that the former. The New Town Market site, which is a flat wetland area now used as cow market, was used for about 10 years with no burning of waste. Decomposable and other wastes were dumped at the site with no sorting or pre-treatment and this led to relatively high groundwater contamination around the area. L3 (spring near Cemetery) and L4 (well at Community Quarters) are very close to this site and show high degree of biological contamination with very shallow groundwater tables. There are also aesthetic problems in this area like constant smell and floods, especially in the rainy season. Moreover, this is an agricultural area with high use of fertilizers, the probable reason for the high concentration of NH_4^+.

Correlations for analysis in Cameroon showed that strong positive correlation between Ca with Mg, and K. This means that they have related sources Ca and Mg are important indicators of construction waste and they also affects the concentration of TDS and TH. Calcium and potassium are components of fertilizer. Magnesium is positively correlation with NH_4^+ and K and lightly with Na and SO_4^{2+}. Almost all parameters are strongly correlated to TH and TDS; a further explanation for the trend in TDS values which implies that the higher the concentration of ions, the higher the TDS; a clear sign of positive correlations. TDS in L6, for example, is highest as L6 has the highest concentration of ions, while L7 has the lowest TDS because which ties with its low ion concentration. Ammonium and potassium show strong positive correlation with tailed value of 0.002, implying a clear conclusion that they are component of Sewage and fertilizer. The correlation between most of the components is an indication that most of them have similar input like sewage, fertilizer, construction waste and other sources or they easily react to form compounds. Correlation values will subsequently help in the selection of adequate methods of treatment and disposal to minimise the level of contamination, and in decision making which will minimise the possible sources of contamination. Most of the strong correlations are backed the tailed values below 0.05.

Analytical results from Cottbus show a slightly different correlation trend. For example, nitrate has correlations with K, Ca, EC m; TDS has slight correlation with Na; Cl^- correlates with sulphate; and K is in the case of Cameroon slightly correlated with nitrate and in the case of Germany with ammonium. Similarities exist in the case of Mg and Ca, TDS and most of the variables. These changes could probably be the effects of storage and transportation on the samples.

Finally, it can be concluded that HYSACAM in Limbe practises a relatively good waste collection and transportation system, which is still undergoing adjustment. However, the method of disposal is not the best and needs to be overhauled. The open-dump method is an unacceptable method with lots of negative impact on man and the environment. The collection of waste sometimes is disturbed by irregular collection due to poor access to collection points. Waste is littered around waste bins and smells. In the slums where collection is rare or non-existent, the local people dump waste in their locally created dumps and pits. These together with the uncontrolled and inappropriate disposal of sewage are a source of risk to the inhabitants. Water samples collected from wells, springs and borehole in these areas were biologically contaminated and need serious treatment. The water should not be used for drinking and household use. L6 is the most contaminated of all sample, while L2 and L7 are the least contaminated. Physico-chemical analysis show lower concentration of analysed parameters than prescribed by given standards except for ammonium which showed values higher than prescribed standards. Serious ammonium treatment as well as biological treatment is required for all sites. As a result, LUC, HYSACAM and other companies are obliged to come up with appropriate and effective methods of waste management which should include the 3Rs, collection, treatment, sorting, disposal (landfill with appropriate barriers) and groundwater monitoring. LUC needs to effectively implement stronger and sustainable legislation and EIA in waste management and disposal which should include constant and long-term groundwater monitoring.

6.2 Recommendations

The centralised system in Cameroon, with everything centred on the capital, Yaoundé, negatively affects the implementation of the very good legislation on waste management. In order to attain maximum implementation and effectiveness of these set regulations, the following recommendations, if considered, will enhance proper and sustainable waste management:

- In order to achieve adequate implementation of rules and regulations radical changes of the current policies and regulatory systems are required. One approach to achieving this would be to implement guidelines such as those developed in the Strategic Planning Guide (SPG) by Wilson et al, (2003) and Read and Wilson, (2003). The Guide lays down procedures for assisting decision makers in actively engaging with all stakeholders in the decision making process ranging from adequately identifying the baseline situation for MSWM in the city, to establishing a framework for the delivery of sustainable waste management solutions. SPG already is a key document in developing economic situations, successfully combining the tools for planning and waste management service delivery (Olley et al, 2006).

- The decentralisation of responsibilities will enhance the creation and implementation of rules. This will ease the work of Councils and waste management companies, who know the situation in their municipality as they will jointly as well as separately create and implement laws and regulations that meet the needs of the people in the municipality.

- The formulation of a comprehensive framework of regulations for waste management (with all relevant tools for its implementation), integrating materials conservation, disposal, groundwater monitoring, public participation and data gathering which reflect the realities of waste in Cameroon should be made.

- The implementation of these waste management laws should be limited to fewer agencies with well-defined roles. Institutional strengthening and cooperation (lateral and vertical) between these agencies should be enhanced. This enhancement should aim at reducing excessive and unnecessary bureaucracy, and introducing transparency and accountability (Wilson et al, 2005). Municipal Councils should be given financial autonomy with more financial resources and greater control.

- Town planning laws should be implemented. This will ease the destruction of slums and subsequently the construction of adequate and accessible streets and roads. As a result, waste collection and hence, management will be easy.

- Regulations on town planning should be implemented so as to ease the destruction of slum area, construct adequate and accessible streets and roads, create a sustainable and affordable town plan and issue building permits according to made plan. This will be a big and positive step to waste collection, disposal and the minimisation of groundwater contamination.

- An increase in public participation will enhance effective waste management through a genuine decentralization of Council control and the empowerment of members of the civil society or community.

- Public education and awareness related to neighbourhood services and issues must be intensified (Wilson et al, 2005; Olley et al, 2006). However, while the civil society can take an active role in awareness raising campaigns, ultimate success would depend on the full backing of the key-decision makers so that stakeholders would feel that they have ownership of the project outcomes (Ball, 2006).

- Strengthening of private-public partnerships in waste management is required. Such successful partnerships can be forged in the areas of material recovery, community composting and final waste disposal. They should, in turn, encourage private investment in the delivery of waste related recycling and recovery facilities (Ahmed and Ali, 2004). In order to establish these partnerships, there is a need for major participative consultation through facilitated workshops involving all key stakeholders like municipal councillors, government agencies, waste contractors and representatives of community groups. The workshops will facilitate the development of all perspectives regarding sustainable waste management and groundwater protection, the building of consensus and the implementation of policies and services (Henry et al, 2006; Wilson et al, 2005).

The method of waste management, especially waste sorting, treatment and disposal in Cameroon in general and Limbe in particular, does not meet conventional standards. Waste is not sorted or treated before disposal. It is simply moved from one point to the next, which implies there is the possibility of environmental pollution, human hazards and groundwater contamination. This study investigated existing methods of waste disposal in Cameroon, with particular reference to Limbe. It also emphasised the importance of different waste disposal methods, especially landfill construction in order to prevent groundwater contamination. As a result, specific measures for improving the current waste management situation in Limbe would include the following:

- Waste management agencies like HYSACAM should comply with the EIA programme of Cameroon in the sector of waste management strategies, site selection and Human resource. EIA should involve historical and current investigations, groundwater conditions, water table, residents around the area, public participation, waste type and volume, drawing different types of maps, climate conditions, land use of the area and other important steps as in Tables 10 an 11.

- Open dumping and burning are methods of waste disposal used at the Karata waste site by HYSACAM. Burning releases toxic substances to the environment. Instead of open dumping, a municipal or containment landfill can be constructed at a well investigated and secure site. If waste (e.g. clinical, municipal, industrial waste) must be co-disposed, a containment landfill can be constructed otherwise, a municipal/sanitary landfill should be constructed. A barrier system should be well constructed with provisions for appropriate leachate and gas collection systems.

- HYSACAM Limbe planned on constructing a new waste disposal site. The planned unit should preferably be a landfill in the form of a project which involves EIA and the following consideration:
    - Site selection and investigation which should consider the steps and information already in chapter three of this study. Public participation should be a very important aspect of the project. The capacity and stability of the site should be seriously taken into consideration.
    - Accessibility of underground position from barrier perspective. According to Knödel et al (2010), it is recommended to use the German barrier method and standards which are more stable and secure.
    - Planned monitoring systems should be included after acquiring information on groundwater condition, depth and flow direction. This should include groundwater monitoring wells which will provide data on the different types of contaminant.
    - The landfill construction plan should also include gas collection system which will minimise atmospheric contamination/pollution. These gases, mostly methane and carbon dioxide, should be used for other purposes like energy production. The European Commission has estimated that 32% of landfill gas is methane, which is 30 times more dangerous than carbon dioxide.
    - Last but not least, the project should involve post groundwater monitoring and gas collection, since the closed site could then be used in different ways.
- Council waste bins should be put in reachable places and emptied more frequently. More collection trucks and bins are needed in Limbe to ease and improve the collection of waste. These trucks should undergo constant checks so as to avoid the problems of waste staying at collection point for too long because of truck break-down.
- A good waste management strategy should strive to avoid waste generation where necessary. However, as long as there is production and consumption, a hundred percent realisation of these remains illusory. Hence, the minimisation of the rate of waste generation remains the best alternative. In this regard, there is need for the public sensitization and education on the re-use of wastes like plastics, metals, papers, clothes and other materials which contribute to reduce the environmental and health impacts of waste. Recycling approaches like composting, are more applicable and appropriate in developing countries where the waste stream contains up to 75% of organic waste which can be effectively converted to compost and biogas production for purposes of manure and energy usage respectively.

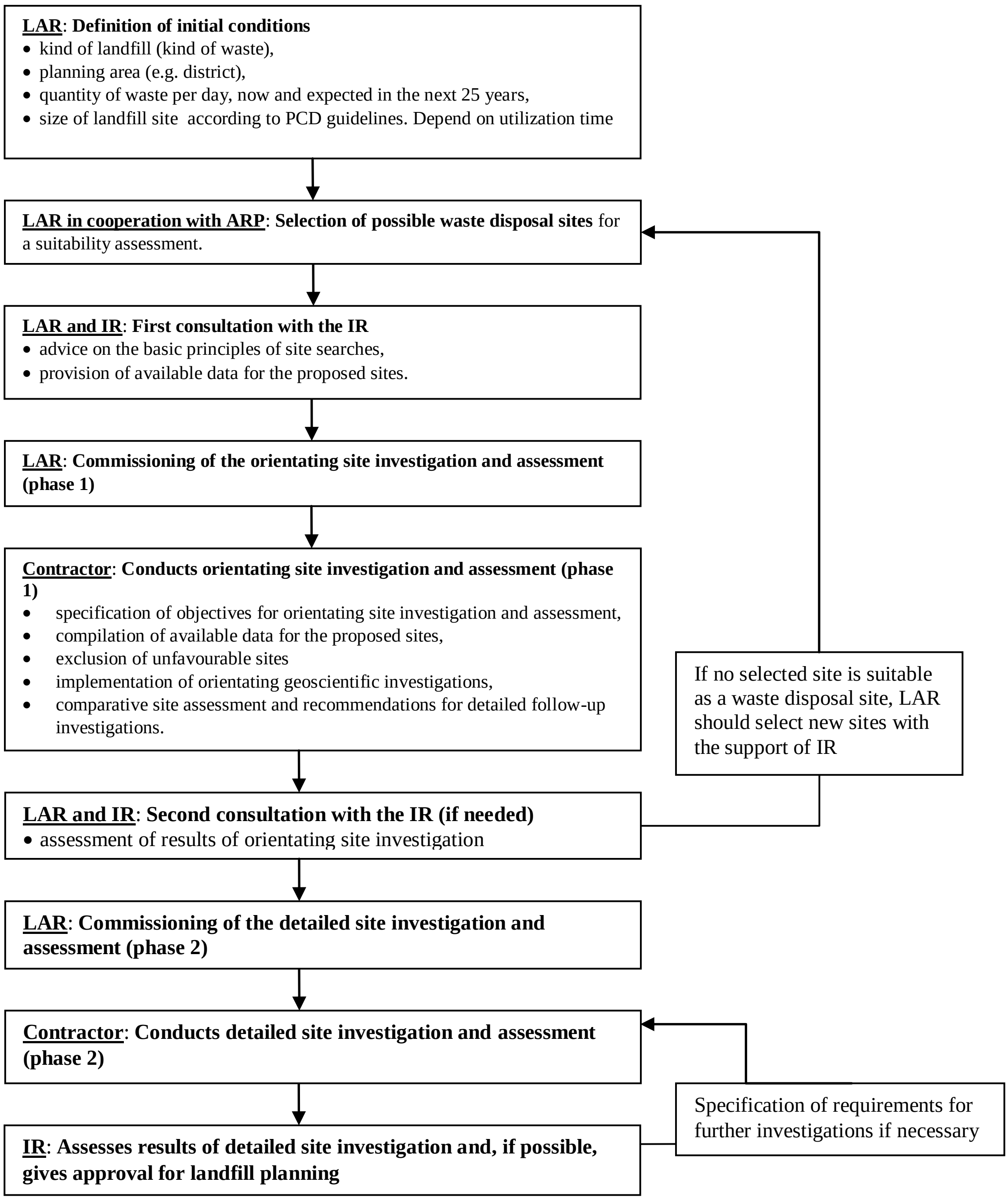


Figure 36: Flow chart for a search for a new waste disposal site (pragmatic approach)

Source: Voigt et al, 2006

The effects of a landfill on groundwater will greatly depend on the barrier system used. In the case of Limbe, the Multiple Barrier Concept (MBC) with man-made (technical) and natural (geological) barriers is strongly recommended (Voigt et al, 2006). The former reduces pollution while the latter act as a component of safety. Geological barriers must only be approved if geophysical, geohydrological, geochemical and hydrochemical studies are carried out. HYSACAM Limbe needs geoscientific investigation and assessment data for Limbe to find the most appropriate site with the most adequate geological barriers. This will require professional techniques and experts who are transparent and free from political influence or entanglement. Information on Figure 36 can be used to ease the process since geoscientific investigation always involves social and political interests. The chart below can be used in cases where no detailed geological and hydrogeological maps are available. This eases decision making as extensive geological and hydrogeological data will be made available. The following participants in the chart are important in site investigation:

1. LAR: local authority responsible, e.g. municipality
2. IR: institution responsible, in some cases more than one institution, e.g. HYSACAM
3. ARP: authority for regional planning
4. Client: LAR for commissioning site investigations
5. Contractor: responsible for handling site investigations commissioned by the client

- Workers should be encouraged through awareness seminars, increased salary and better working conditions. They should be provided appropriate clothing (protective shoes and clothes), constant medical checks paid by the company, better cleaning equipment and fixed working time (at best in shifts). The employees should be trained on the methods and importance of proper waste disposal. This should involve the encouragement of sustainable methods of waste management. The most important part of waste management will be the at-the-source processing of MSW as in Figure 37. The main objective of this process should be to reduce the volume of MSW to be disposed of, encourage reuse of waste material and recycling what is recyclable.

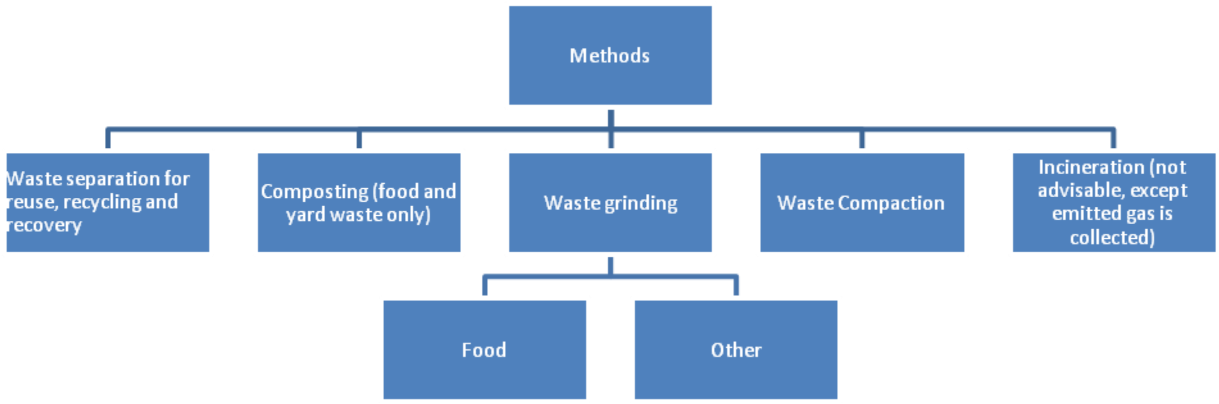


Figure 37: Proposed steps for processing MSW at the source adapted from Notes of Prof. Gunter Busch

- Another achievable means of waste reduction is through self information on the life span of a product, possibility of maintenance, repair or restoration of the product with time and availability of alternatives which are less complex or wasteful. Waste separation and recycling are very important steps in waste reduction. Separation of waste into different types like biodegradable waste, recyclable materials, plastics and metals, minimises adverse effects on groundwater.

- Waste sorting will cause the creation of jobs for the local people; as well, it increases the quality of each type of waste, e.g. organic waste, plastics, bottles, and recyclable and reusable waste. Sorting also reduces the amount of waste for final disposal at landfill and eases waste treatment before final disposal.

- Degradable waste can be composted and used as manure. This process referred to as composting can be better managed in small scale. Municipal solid waste in most developing countries has up to 75% of organic waste which can be transformed to a plant-friendly humid substance called compost (Amera, 2009). This is achieved by using water and oxygen to ease the degradation process by aerobic bacteria. This takes a few months and requires frequent mixing and addition of small amounts of water to hasten the process. This process releases carbon dioxide and energy; reduces the amount of waste to be dumped in a landfill, cost in collection, transportation and disposal of waste; improved hygienic and health conditions; improves water holding capacity of the soil, structure and stability thereby preventing soil degradation and erosion. This also increases crop yield, generates income, minimises the importation, use and effects (release of ammonia. Composting involves thorough sorting of solid waste and so enhances job creation for the local people.

- Waste recycling will imply sending metals to metal recycling companies like ALUCAM for Al recycling, batteries to Pilcam Batteries, paper to paper recycling companies like Samco Papers, and bottles and plastic containers could be returned to various companies for recycle and reuse. Plastics can also be thermally heated for energy production taking the minimisation of pollution into special consideration. However, waste recycling also has contaminating effects, and in some cases incineration and other treatment methods are advisable.

- Waste incineration on the other hand reduces waste for landfilling, even though it has many adverse effects. This method of waste reduction can only be used if an appropriate incineration system is constructed that complies with international norms because this could release very toxic substances which are harmful to man and the environment. Incineration ash has high amounts of harmful substances like SO_4 and magnesium, which can be treated and dumped in landfill, whereas gas released can be collected and used for various purposes.

Groundwater results from this study can be used as the basis of the current state of groundwater in Limbe. Further groundwater research (analysis and monitoring) is required to enhance the elimination and prevention of contamination. Groundwater monitoring is very important and helps to minimise groundwater contamination, particularly portable water. As a result, the following steps if considered will assist the understanding of groundwater problems in Limbe:

- Before a new site is constructed, it is important to undertake groundwater research in Limbe and the Karata dump site. This would further ease site selection and provide information on groundwater at Karata site.

- Further groundwater analysis must be carried out and documented, especially areas with poor toilet conditions, excessive sewage release, waste litter and open dumps. For example, microorganisms as well as phosphate and ammonium (showed high concentration in all samples) should be analysed especially as they are contaminants from domestic sewage, agricultural effluents, detergents and industrial waste water (Patil and Patil, 2010).

- The water used for drinking should also undergo analysis to assess whether it is good for human consumption. Drinking water is provided by SNEC/CAMWATER.

- Groundwater monitoring should be introduced in Limbe to enhance decision making on the groundwater management and wastewater treatment. Groundwater monitoring provides constant and continuous information on groundwater as well as information on water components/contaminants, thereby influencing treatment and maintenance methods. This will ease site selection and landfill construction in that the barrier system can be decided upon as well as the method of leachate collection.

From results obtained, groundwater treatment is unavoidably required in Limbe as well as further statistical analysis and modelling of long-term groundwater analysis and monitoring is needed. Projects can be proposed and implemented which will lead to the employment of people and poverty alleviation. This study can be used as a base for further research since it gives a current background of groundwater situation in some, but most populated parts of the city.

SNEC/CAMWATER Limbe should reconsider its method of water treatment and storage, and embark on intensive and cost-effective ways of water management for drinking purposes. It should most importantly include groundwater monitoring in order to locate contamination sources and ways in which this can be minimised. This would enhance the goal of providing portable water for the Municipality. Sewage collection and treatment should also be included in the wastewater management plan as it will minimise groundwater contamination. This seems to be the major source of biological pollution of groundwater.

The Cameroon National Radio, (2011), confirmed the high contamination level when it announced that at least 70% of Cameroonians lack access to potable water. People carry water from wells near pit toilets, hence the current wave of cholera in the country. As a result, shallow wells should no longer except for washing floors, cars and flushing toilets because of its excessive biological contamination. The quality of most of them is too low to warrant treatment, even though intensive treatment is required. Boreholes should be dug at accessible and groundwater-safe areas, while water in shallow wells should be well treated and pipe-borne water checked for contamination before further use. Groundwater analysis is needed and hence, the Council should consider a project that will lay emphasis on analysing groundwater in the Limbe vicinity.

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APPENDICES

Appendix I: Waste Collection Programme for HYSACAM

HYSACAM LIMBE
B.P. 190
TEL. 33 33 30 76
FAX. 33 33 30 67

GARBAGE COLLECTION PROGRAME

Camion No 33

DAILY

LIMBE I

SECTEUR I

- Main Road Bota :
- PMI Road
- Clerks quarter
- Down Beach :
- MOTOMBI Street
- Mbonjo Road:
- Main Street:
- Church Street
- Manga William Avenue
- New Town tarred Road

DEBUT SECTEUR

- Container customs
- **Centenary stadium** jusqu' à Kings William Square
- **PMI Road** jusqu' au Travaux Public
- **Manga William Avenue** demi
- **Mbonjo Road** jusqu' au fin goudron
- **Down Beach Road** jusqu' à Kings William Square
- **Main Street:** De King William Square jusqu'au carref. Idénau
- **Church Street:** De Half Mile – Flea market jusqu' à Santiago

New Town tarred Road: Adamou Streetjusqu' à l'auberge Paradis

- **Carl Street:** De Immeuble Cabelo à Immeuble la Maman
- **Motombi Street:** De Man A Man Jonction à Immeuble Cabelo
- **Clerks quarters et Down Beach:** Du container à coté de la sous-préfecture à Boys School
- **De SCPDM** à la maison de parti plus la cité de L.C.C.
- Route passant devant AES SONEL
- **Manga William Avenue:** De Travaux Public à Saker Jonction.
- Terminer le secteur par Old Market, New Market et resortir par Behind Police Barracks.

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HYSACAM LIMBE
B.P. 190
TEL. 33 33 30 76
FAX. 33 33 30 67

GARBAGE COLLECTION PROGRAME

Camion No 05 *LUNDI – MERCREDI - VENDREDI*

LIMBE I **SECTEUR II**

- Mbende
- Community quarter
- Gardens
- Indian quarter
- G.RA.
- Cité Sic
- Opposite Cité Nanga
- S.S. Quarter

DEBUT SECTEUR:

- **Mbende:** De l'entrée de Mbende à Ambass Bay
- **Community quater:** Sur toutes les pénétrantes derrière L.C.C
- **BOTANIC Garden:** Partant de l'entrée du Jardin BOTANIC jusqu' à Atlantic Beach Hotel
- **Main Road Garden:** De TEXACO à FIFFA Banque, inside Garden et la sortie par the The Coach
- **Main Road Bota:** De FIFFA Banque par L.C.C – Police Station

  Zoo – Treasury – Bota Camp Two - main road Bota -Bota customs jusqu' au carref. KARATA – Main road oppositeCité Sic.
- **S.S. Quarter:** De CDC Head Office et toutes les routes de l'interieur jusqu' à la sortie par l'école PNEU
- **Bota Camp One:** De Open Gate restaurant à Indian quarter

Rose Bowl – Behind Rose Bowl plus les pénétrantes qui suivent – Cottage Grill jusqu' à la Base HYSACAM et retour sur GRA en passant par SONEL Flate jusqu' au Fond National de l'emploi en plus jusqu' au domicile DG CDC et retour à GRA Boutiques et toutes les pénétrantes jusqu' au Camp millitaire Delta, plus la route non goudronnée passant à côté de l'église Presbiterinne de GRA et retrouver la Cité Sic passant par la route qui passe en bas de SAVOY PALMZ.

Cité Sic: Prendre la route passant devant la salle de Temoins de JEHOVA,Bilingual Training centre sur main Road Cité Sic jusqu' au Zoo allée et retour sur la première route au mur de Trade Fare de la Cité Sic et toutes les pénétrantes.

Opposite Cité Nanga: Brettele derrière SAVOY PALMZ

De la pénétrante après SAVOY PALMZ passant par NHIS(New Horizon Internationa School) jusqu' à ITS (Intertek)testing services et la sortie sur main road opposite Cité Sic et Fin secteur.

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HYSACAM LIMBE
B.P. 190
TEL. 33 33 30 76
FAX. 33 33 30 67

GARBAGE COLLECTION PROGRAME

Camion No 65 — *LUNDI – MERCREDI - VENDREDI*

LIMBE I — **SECTEUR III**

- Coconut Island
- Cassava Farms
- Lumpsum
- New Town untarred Road
- Mabeta New-Layout
- Mawoh quarter
- Potopoto quarter
- Dockyard

DEBUT SECTEUR:

- **Coconut Island:** De Taxation office derrière Community field, faire pénétrante derrière le stade et continuer la collecte jusqu' à main road Gardens
- **Cassava Farms:** Entrer par Marshall Home et faire toute la boucle.
- **Lumpsum:** Partant du drain de Lumpsum jusqu' à derrière Sea Palace – Reprendre par l'entrée de Holiday Inn jusqu' à la monte de Upper Towé
- Faire la route du cimetière de Lumpsum
- **New -Town untarred Road:** De l'église Adventiste du 7ème jour jusqu' à Saker Street
- **Mabeta New Layout:** De Saker Street allée au fond de Mabeta et retour à Saker Jonction et toutes les autres transversalles jusqu' au Pont Mawoh Bridge
- **Mawoh quarter:** De Mawoh bridge à Mondial Spot bar et retour jusqu' à l'église Appostolic church de Mawoh – collecter petit Motowoh et resortir pour Motowoh quarter.
- **Motowoh quarter:** De fin goudron à New Town à l'entrée principale de Motowoh jusqu' au Grand carreffour derrière FATECOL.
- **Potopoto quarter:** Du carreffour Fatecol jusqu' au cimetière de New Town et resortir par le labattoir de Limbé
- **Dockyard:** De l'entrée de Boukarrots jusqu' à la courbe de Ernesco Soya et ressortir par la route Mbonjo – collecter toutes les pénétrantes du côté des écoles Publics de Down Beach

HYSACAM LIMBE
B.P. 190
TEL. 33 33 30 76
FAX. 33 33 30 67

GARBAGE COLLECTION PROGRAME

Camion No 65 — *MARDI – JEUDI - SAMEDI*

LIMBE I — **SECTEUR IV**

- Middle farms
- Espoir
- Quartier Face Depot Guiness
- Comprehensive
- Animal Farms – caterpillar Field
- Alpha club
- Unity quarter

DEBUT SECTEUR:

- **Middle farms:** Partant de la route sortant de la Base jusqu' au carref. Bota Hospital -collecter toute la boucle de Middle farms.
- **Quartier Espoir:** De Limbé camp plus les pénétrantes jusqu' à Mile one.
- **Quartier Face Depot Guiness:** Collecter toutes les pénétrantes jusqu' à côté carref. Edenau
- **Comprehensive:** De Bahai jusqu' à la montée glissante et de la montée glissante jusqu' à behind SNEC
- **Animals Farms:** De Behind SNEC au rond point Animal Farms et du rond point Animal Farms au petit terrain Caterpillar Field.
- **Du petit terrain** passant par Animal Farms, Batié col jusqu' au cours d'eau Towé
- BIFUNDE- Victoria Bakery
- **Montée de Towé** allée et retour jusqu' au carref. Alpha Club
- **Alpha club:** Du carref. Alpha Club, derrière Comprehensive, jusqu' au cours d'eau Alpha Club allée et retour jusqu' à Behind SNEC
- **Unity quarter:** De l'hôpital Provincial à Unity quarter garage et continuer la collecte jusqu' à la descente Eden Radio

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HYSACAM LIMBE
B.P. 190
TEL. 33 33 30 76
FAX. 33 33 30 67

GARBAGE COLLECTION PROGRAME

Camion No 62 — *LUNDI - MERCREDI - VENDREDI*

LIMBE I — **SECTEUR V**

- Limbé Camp
- Main Road Mile Four
- Mile Seven Camp
- Maternity quarter

- **Limbé Camp:** Collecter la boucle de Medécine Shoppe
  Faire le tour de Limbé Camp et toutes les rues de l'interieur.
- Route du collège Exellence
- **Main Road Mile Four:** Du carreffour Idénau jusqu' à l'entrée du Mile Seven Camp
  Faire Mile Seven Camp et retour à Maternity quarter
- **Maternity Quarter :** Entrer par Crédit Union, passer par Eglise Appostolic, Contourner maternity clinique
  et resortir par le long des écoles face Mile Four Park.
- Faire la route qui mène au coffre opposite Mile four Park
- Faire le tour de Mile Four Park

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HYSACAM LIMBE
B.P. 190
TEL. 33 33 30 76
FAX. 33 33 30 67

GARBAGE COLLECTION PROGRAME

Camion No 62 — *MARDI – JEUDI - SAMEDI*

LIMBE I — **SECTEUR VI**

- Moussoumbou Camp
- Samco quarter
- Moliwé
- Quarter 14
- Quarter 6
- Route Bojongo
- Wututu Park
- Main Road Garden
- Inside Garden

- **Mile Three:** Collecter la boucle de Moussoumbou Camp
- **Samco quarter:** Faire les (trois pénétrantes)
- **Main Road Mile Four:** De la sortie de Samco quarter à l'entrée de Moliwé
- **Moliwé:** Contourner le (camp CDC ouvriers) plus
- **Moliwé:** Camp ingenieurs CDC + BehindMile Four Park
- Main Road Garden: De TEXACO FIFFA + inside Garden de FIFFA à l'entrée de Mbende
- **Quarter 14:** Route à côté Mile Four Park et monter jusqu' à derrière temple de Temoins de JEHOVA recontinuer la collecte jusqu' à l'interieur du quartier et retrouver Atlantic quarter derrière Safari Bar
- **Quarter 6:** Du derrière Safari bar jusqu' à quarter 12 derrière le marche de Mile Four
- Prendre la route qui mène à la citerne d'eau de Mile Four (Water Tank)
- **Route Bonjongo:** De l'usine à café à Wututu park
- **Wutu Park:** Entrer etresortir + la pénétrante du marché Mile Four
  Finir la collecte à la sortir de main road Mile Four

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HYSACAM LIMBE
B.P. 190
TEL. 33 33 30 76
FAX . 33 33 30 67

GARBAGE COLLECTION PROGRAME

Camion No 05 — *MARDI – JEUDI - SAMEDI*

LIMBE II — **SECTEUR VII**

- Batoke
- Main road Batoke
- Inside Wovia
- Inside Botaland
- Isokolo New- Road et Old Road
- Isokolo untared

- **Isokolo New Road:** De carref KARATA jusqu' à l'entrée de Wovia
- **Isokolo Old Road:** De l'entrée Wovia au Rond point Karata
- **Isokolo untarred Road:** CDC Camp Karata: Collecter tout l'interieur du camp
- Route à côté de CDC camp
- Pénétrantes GT (Government Technical College) et redescendre sur la seconde rue avec brette à droite jusqu' au petit marché Isokolo
- G.N.S(Government Nursery School) jusqu' à Big Time Bar
- Road opposte Primary Shool sur New Road allée et retour
- Entrée samrock Cottage jusqu' à l'église presbiteriens de Isokolo
- **Batoke côté chefferi:** Deuxpénétrantes
- **Batoke côté opposé à la chefferie:** Trois pénétrantes
- **Batoke:** De Batoke passant par Monkundange – Bobende – pénétrante Reinco Hotel – Nguémé - InsideNguémé - Nguémé New-Layout jusqu' à l' entre de Wovia
- **Inside Wovia:** Collecter tout le quartier
  Collecter la route de Coutyard Hotel jusqu' à Old Road Isokolo + deux pénétrantes
- **Inside Botaland:** Collecter toute le quartier et reviser New et Old road Isokolo

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Appendix II: Laboratory Certificate from CBC Mutengene-Cameroon

CBC CENTRAL PHARMACY

QUALITY ASSURANCE DEPARTMENT

CERTIFICATE OF ANALYSIS

17-05-10

Seven water samples were collected according to official norms for current Good Laboratory Practices (GLP) at different locations within Limbe Municipality in the South West Region of Cameroon on the 19th of April 2010. Research work ordered by Mrs. Adeline Abimnwi AWEMO CHEO, a Doctorate research student from the Brandenburgiche Technische University, Cottbus-Germany.

Type of analysis carried out: MICROBIAL and PHYSICO-CHEMICAL

Date of analysis: 21-04-10 to 05-06-10

MICROBIAL ANALYSIS

SAMPLE CODE	ORGANISM(S) FOUND	POSSIBLE SOURCE(S)	Count (CFU/100ml)	Cameroon stds. (CFU/100ml)	Comments
L1	*Total Coliforms (Enterobacter , Citrobacter* and *Klebsiella* sp) *Escherishia coli* (E. coli)	Faecal matter, soil and sewage. Same as above	543 26	<1/250ml Absent/100mL	RESULTS INDICATE THAT WATER SOURCES NEED TO BE TREATED SERIOUSLY
	Staphyloccocus sp.	Skin	24 /100ml	NA	
L2	*Total Coliforms (Enterobacter , Citrobacter* and *Klebsiella* sp) *Escherishia coli*	Faecal matter, Soil, sewage Same as above	>1000 205	<1/250ml Absent/100ml	
L3	*Total Coliforms (Enterobacter, Citrobacter* and *Klebsiella* sp) *Escherishia coli*	Faecal matter, soil, sewage Same as above	>1000 346	<1/250ml Absent/100ml	
	Salmonella sp.	Faecal matter, sewage	103	Absent/100ml	

L4	*Total Coliforms (Enterobacter , Citrobacter* and *Klebsiella* sp) *Escherishia coli*	Faecal matter, soil, sewage Same as above	>1000 256	<1/250ml Absent/100ml	
	Salmonella sp.	Faecal matter, sewage	94	Absent/100ml	
	Faecal streptoccocus	Faecal matter, Soil sewage	159	<1/250ml	
L5	*Total Coliforms (Enterobacter , Citrobacter* and *Klebsiella* sp) *Escherishia coli*	Faecal matter, soil, Sewage Same as above	735 102	<1/250ml Absent/100ml	RESULTS INDICATE THAT WATER SOURCES NEED TO BE TREATED SERIOUSLY EXCEPT FOR **L7** THAT NEEDS MILD TREATMENT
	Salmonella sp.	Faecal matter, sewage	56	Absent/100ml	
	Faecal streptoccocus	Faecal matter, Soil sewage	87	<1/250ml	
L6	*Total Coliforms (Enterobacter , Citrobacter* and *Klebsiella* sp) *Escherishia coli*	Faecal matter, soil, sewage Same as above	>1000 157	<1/250ml Absent/100ml	
	Salmonella sp.	Faecal matter, sewage	102	Absent/100ml	
	Staphylococcus aureus	Faecal matter, Skin sewage	205/100ml	NA	
L7	*Total Coliforms (Enterobacter , Citrobacter* and *Klebsiella* sp) *Escherishia coli*	Faecal matter, soil, sewage Same as above	06 04	<1/250ml Absent/100ml	
	Staphylococcus aureus	Faecal matter, soil, sewage	08 /100ml	NA	
	Pseudomonas sp.	Faecal matter, soil, sewage	03	Absent/100ml	

KEY

L1: Cold water spring

L2: Spring near cemetery

L3: Well 1, near cemetery (Motowoh)

L4: Community Quarters

L5: Motowoh hill

L6: Clerks Quarters

L7: Karata bore-hole

NA: Not Available

CFU: Colony forming units

PHYSICO-CHEMICAL ANALYSIS

PARAMETERS (mg/L)											
CODE	**Ca^{2+}**	**Mg^{2+}**	**Cl^-**	**HCO_3^-**	**SO_4^{2-}**	**TDS**	**Total Hardness**	**Na^+**	**NO_3^-**	**NH_4^+**	**K^+**
Standard	**<100**	**<30**	**<250**	**<305**	**<250**	**NA**	**NA**	**<175**	**<50**	**<0.5**	**<12**
L1	16.05	19.47	78.70	14.01	50.56	360	100.09	3.80	3.70	1.90	5.30
L2	20.06	19.47	39.30	2.00	36.54	284	78.07	2.20	37.80	0.90	2.10
L3	28.08	24.33	59.00	22.02	43.68	400	118.11	2.30	13.80	1.60	5.00
L4	32.09	29.20	68.90	17.02	29.79	424	108.10	3.00	28.10	1.80	6.00
L5	24.07	17.03	59.00	10.01	16.90	376	68.06	1.50	28.50	0.90	2.60
L6	64.19	51.10	59.00	10.01	66.87	920	192.17	4.10	118.10	2.60	13.60
L7	8.02	19.47	29.50	2.00	18.55	276	48.04	1.70	2.60	1.30	4.70

KEY

L1: Cold water spring

L2: Spring near cemetery

L3: Well 1, near cemetery (Motowoh)

L4: Community Quarters

L5: Motowoh hill

L6: Clerks Quarters

L7: Karata bore-hole

NA: Not Available

Appendix III: Certificate of Results from BTU Cottbus, Germany

Analysis in Cottbus, Germany:

Results of analysis

Please find attached the results from your Cameroon samples. I charged balanced HCO3, which always gave positive values. However, the geochemical modeling (phreeqc), which also considers things like phase equilibria and pH, did not always converge and, if converged, produced carbonate values below the ones given by the charge balance.

As for Fe, pH is so high that the Fe (III) phase saturation indices calculated by phreeqc are substantially >0, which is a clear indication of precipitation of Fe compounds. This was obvious in sample L4, where we observed a yellowish-brownish precipitate. In such case one must assume Fe (II) in the original sample, which was oxidized during transportation from Cameroon. This consideration is independent from the charge balance, because Fe precipitation is a pH buffering mechanism. We measured pH, so the charge should balance anyway. (L4 converged well in phreeqc)

For QC we applied the WMO criteria, which check both charge balance and EC measured vs. EC calculated from analysis results. All samples except L7 passed QC with no problems. The QC criterion for L7 is almost met; we have 22% EC error instead of 20% required. Because we have no options for additional analyses and because HCO3 was charged balanced, I believe that there is no reason for concern in that matter. (Mathematically I could use the trick to violate the charge balance, still leaving it inside the QC limits for charge balance, thus bringing EC down to 20%).

Apart from this, you were also interested in TDS. I calculated TDS from both analysis results and from measured EC, where I used the conversion factor EC -> TDS as a plausibility check. It should be in the range from 0.5 to 0.8. The best fit is achieved with an average factor of 0.62, which is plausible for the solution chemistry determined.

Please, come to our lab and take the samples. The amount left should suffice for B.

Results

Sample No.	pH	Cl mg/l	NO3 mg/l	SO4 mg/l	HCO3*) mg/L
L1	7,14	1,57	2,06	2,28	117,09
L2	6,22	19,12	35,12	6,35	22,68
L3	7,15	22,23	7,56	10,30	79,81
L4	7,57	13,04	18,55	9,66	98,68
L5	6,73	9,02	24,45	2,70	38,95
L6	7,08	22,06	101,86	12,51	101,82
L7	7,42	1,36	1,07	1,80	64,50

*) charge balance

Sample No.	Na mg/l	NH4 mg/l	K mg/l	Mg mg/l	Ca mg/l	Al mg/l	Mn mg/l	Pb µg/L
L1	12,07	<0,1	3,59	9,55	12,83	<0,3	<0,05	<5
L2	14,47	<0,1	1,41	5,78	9,35	<0,3	<0,05	<5
L3	14,74	0,59	3,56	8,44	16,23	<0,3	<0,05	<5
L4	19,46	0,94	4,21	7,22	17,70	1,15	<0,05	<5
L5	8,58	<0,1	1,73	4,34	11,37	<0,3	<0,05	<5
L6	25,54	1,11	12,04	14,20	30,89	<0,3	<0,05	<5
L7	10,60	<0,1	3,40	4,59	4,49	<0,3	<0,05	<5

Sample No.	EC meas. µS/cm	EC calc. µS/cm	EC error WMO-GAW-criteria	EC QC	TDS**) mg/L
L1	222	167	14,1%	pass	138
L2	218	164	14,1%	pass	136
L3	274	208	13,8%	pass	170
L4	292	226	12,6%	pass	182
L5	173	127	15,4%	pass	108
L6	506	410	10,5%	pass	315
L7	155	100	21,8%	alert	96

**) 0,62*EC